

The Pearson
**Question Bank
for Electronics
& Communication
Engineers**
(PSUs/GATE/IES)

Satish K. Karna

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for
Electronics and Communication
Engineers
(PSUs/GATE/IES)

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Satish K. Karna

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Preface

This book has been primarily developed for the students/engineers who are looking for a bright career in the field of Electronics and Communication Engineering.

These days more and more objective type questions are being asked in various competitive examinations to test real knowledge of students. Thus, the present day trend of competitive examinations with objective type questions is aimed at evaluating the conceptual and mathematical skills of the examinees. Almost all leading public and private sector organizations are conducting such tests for the recruitment of engineer trainees as well as management trainees. With large number of candidates appearing in such tests every year, the competition has become tough. Therefore, for success in such tests, one must be familiar with the style of questions generally asked, and practice solving these questions and get the correct answer.

There are basically *Three Levels of Multiple Choice Questions* that are asked.

Level 1 that needs the concept, basic knowledge and implementation of technical skills very quickly. In such case, the number of questions is, 180 or 200 and the time allotted is 2 hours. In this category, diploma level NTPC, BHEL, SAIL, GAIL, AAI, ECIL, NHPC, IOCL ONGC, OIL ISRO, BEL, RLY, PSEB examinations fall. (Here approximately 100 questions from concerning technical branch and approximately 100 questions are asked from general ability/aptitude section.)

Level 1 and 2 type questions need the concept, basic knowledge with the numerical skills to solve the problems in short time. The number of questions is 240 or 200 and the time allotted is 2:30 or 2:00 hours. In such categories B.Tech level NTPC, BHEL, SAIL, GAIL, AAI, ECIL, NHPC, IOCL ONGC, OIL ISRO, BEL, RLY, PSEB examinations fall. (Here approximately 100 questions from concerning technical branch and approximately 100 questions are asked from general ability/aptitude section.)

Level 2 and 3 type questions need the concept, basic knowledge with the mathematical skills to solve the problems in short time. The number of questions is 65 or 85 or 120 and 150 and the time allotted is 3 hours. In such categories B.Tech, GATE, ISRO, BARC, CSIR, JTO and DRDO examinations fall.

To develop this book, we have *consulted a number of students* who *qualified different examinations previously*. We have collected the memory based questions and analyzed the pattern. We have put full effort to make this book useful for students/engineers.

There are number of books available in markets which contain large number of questions and answers. We have developed a book which contains thousands of questions and answers with the *detailed solutions*. This will help the students to correct the fundamentals and apply to the similar problems that they may face in competitive examinations.

This book consists of thirteen chapters namely, *Materials and Components, Physical Electronics, Electron Devices and ICs, Signals and System, Network Theory, Electromagnetic Theory, Electronic Measurements and Instrumentation, Analog Electronic Circuits, Digital Electronic Circuits, Control Systems, Communication Systems, Microwave Engineering and Computer Engineering*. *Bibliography* given at the end of the text aims to stimulate the readers to go in for further reading to seek in-depth knowledge.

For general ability/aptitude test, students are advised to read the related topic books and practice it. General topics also play a major roll in selection.

Constructive criticism and positive suggestions for the improvement of the quality or the content of this book will be highly appreciated.

Satish K. Karna

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DRDO: Syllabus for Electronics and Communication Engineering

NETWORKS

Network graphs: matrices associated with graphs; incidence, fundamental cut set and fundamental circuit matrices. Solution methods: nodal and mesh analysis. Network theorems: superposition, Thevenin and Norton's maximum power transfer, Wye-Delta transformation. Steady state sinusoidal analysis using phasors. Linear constant coefficient differential equations; time domain analysis of simple RLC circuits, Solution of network equations using Laplace transform: frequency domain analysis of RLC circuits. 2-port network parameters: driving point and transfer functions. State equations for networks.

ELECTRONIC DEVICES

Energy bands in silicon, intrinsic and extrinsic silicon. Carrier transport in silicon: diffusion current, drift current, mobility, and resistivity. Generation and recombination of carriers. p-n junction diode, Zener diode, tunnel diode, BJT, JFET, MOS capacitor, MOSFET, LED, p-I-n and avalanche photo diode, Basics of LASERS. Device technology: integrated circuits fabrication process, oxidation, diffusion, ion implantation, photolithography, n-tub, p-tub and twin-tub CMOS process.

ANALOG CIRCUITS

Small Signal Equivalent circuits of diodes, BJTs, MOSFETs and analog CMOS. Simple diode circuits, clipping, clamping, rectifier. Biasing and bias stability of transistor and FET amplifiers. Amplifiers: single and multi-stage, differential and operational, feedback, and power. Frequency response of amplifiers. Simple op-amp circuits. Filters. Sinusoidal oscillators; criterion for oscillation; single-transistor and op-amp configurations. Function generators and wave-shaping circuits, 555 Timers. Power supplies.

DIGITAL CIRCUITS

Boolean algebra, minimization of Boolean functions; logic gates; digital IC families (DTL, TTL, ECL, MOS, CMOS). Combinatorial circuits: arithmetic circuits, code converters, multiplexers, decoders, PROMs and PLAs. Sequential circuits: latches and flip-flops, counters and shift-registers. Sample and hold circuits, ADCs, DACs. Semiconductor memories. Microprocessor(8085): architecture, programming, memory and I/O interfacing.

Fourier series, continuous-time and discrete-time Fourier Transform, DFT and FFT, z-transform. Sampling theorem. Linear Time-Invariant (LTI) Systems: definitions and properties; causality, stability, impulse response, convolution, poles and zeros, parallel and cascade structure, frequency response, group delay, phase delay. Signal transmission through LTI systems.

CONTROL SYSTEMS

Basic control system components; block diagrammatic description, reduction of block diagrams. Open loop and closed loop (feedback) systems and stability analysis of these systems. Signal flow graphs and their use in determining transfer functions of systems; transient

and steady state analysis of LTI control systems and frequency response. Tools and techniques for LTI control system analysis: root loci, Routh-Hurwitz criterion, Bode and Nyquist plots. Control system compensators: elements of lead and lag compensation, elements of Proportional-Integral-Derivative (PID) control. State variable representation and solution of state equation of LTI control systems.

COMMUNICATIONS

Random signals and noise: probability, random variables, probability density function, autocorrelation, power spectral density. Analog communication systems: amplitude and angle modulation and demodulation systems, spectral analysis of these operations, superheterodyne receivers; elements of hardware, realizations of analog communication systems; signal-to-noise ratio (SNR) calculations for amplitude modulation (AM) and frequency modulation (FM) for low noise conditions. Fundamentals of information theory and channel capacity theorem. Digital communication systems: pulse code modulation (PCM), differential pulse code modulation (DPCM), digital modulation schemes: amplitude, phase and frequency shift keying schemes (ASK, PSK, FSK), matched filter receivers, bandwidth consideration and probability of error calculations for these schemes. Basics of TDMA, FDMA and CDMA and GSM.

ELECTROMAGNETICS

Elements of vector calculus: divergence and curl; Gauss' and Stokes' theorems, Maxwell's equations: differential and integral forms. Wave equation, Poynting vector. Plane waves: propagation through various media; reflection and refraction; phase and group velocity; skin depth. Transmission lines: characteristic impedance; impedance transformation; Smith chart; impedance matching; S parameters, pulse excitation. Waveguides: modes in rectangular waveguides; boundary conditions; cut-off frequencies; dispersion relations. Basics of propagation in dielectric waveguide and optical fibers. Basics of Antennas: Dipole antennas; radiation pattern; antenna gain.

Gate EC - Electronics and Communication Engineering

ENGINEERING MATHEMATICS

Linear Algebra: Matrix Algebra, Systems of linear equations, Eigen values and eigen vectors.

Calculus: Mean value theorems, Theorems of integral calculus, Evaluation of definite and improper integrals, Partial Derivatives, Maxima and minima, Multiple integrals, Fourier series. Vector identities, Directional derivatives, Line, Surface and Volume integrals, Stokes, Gauss and Green's theorems.

Differential equations: First order equation (linear and nonlinear), Higher order linear differential equations with constant coefficients, Method of variation of parameters, Cauchy's and Euler's equations, Initial and boundary value problems, Partial Differential Equations and variable separable method.

Complex variables: Analytic functions, Cauchy's integral theorem and integral formula, Taylor's and Laurent's series, Residue theorem, solution integrals.

Probability and Statistics: Sampling theorems, Conditional probability, Mean, median, mode and standard deviation, Random variables, Discrete and continuous distributions, Poisson, Normal and Binomial distribution, Correlation and **regression analysis**.

Numerical Methods: Solutions of non-linear algebraic equations, single and multi-step methods for differential equations.

Transform Theory: Fourier transform, Laplace transform, Z-transform.

ELECTRONICS AND COMMUNICATION ENGINEERING

Networks: Network graphs: matrices associated with graphs; incidence, fundamental cut set and fundamental circuit matrices. Solution methods: nodal and mesh analysis. Network theorems: superposition, Thevenin and Norton's maximum power transfer, Wye-Delta transformation. Steady state sinusoidal analysis using phasors. Linear constant coefficient differential equations; time domain analysis of simple RLC circuits, Solution of network equations using Laplace transform: frequency domain analysis of RLC circuits. 2-port network parameters: driving point and transfer functions. State equations for networks.

Electronic Devices: Energy bands in silicon, intrinsic and extrinsic silicon. Carrier transport in silicon: diffusion current, drift current, mobility, and resistivity. Generation and recombination of carriers. p-n junction diode, Zener diode, tunnel diode, BJT, JFET, MOS capacitor, MOSFET, LED, p-i-n and avalanche photo diode, Basics of LASERS. Device technology: integrated circuits fabrication process, oxidation, diffusion, ion implantation, photolithography, n-tub, p-tub and twin-tub CMOS process.

Analog Circuits: Small Signal Equivalent circuits of diodes, BJTs, MOSFETs and analog CMOS. Simple diode circuits, clipping, clamping, rectifier. Biasing and bias stability of transistor and FET amplifiers. Amplifiers: single and multi-stage, differential and operational, feedback, and power. Frequency response of amplifiers. Simple op-amp circuits. Filters. Sinusoidal oscillators; criterion for oscillation; single-transistor and op-amp configurations. Function generators and wave-shaping circuits, 555 Timers. Power supplies.

Digital circuits: Boolean algebra, minimization of Boolean functions; logic gates; digital IC families (DTL, TTL, ECL, MOS, CMOS). Combinatorial circuits: arithmetic circuits, code converters, multiplexers, decoders, PROMs and PLAs. Sequential circuits: latches and flip-flops, counters and shift-registers. Sample and hold circuits, ADCs, DACs. Semiconductor memories. Microprocessor(8085): architecture, programming, memory and I/O interfacing.

Signals and Systems: Definitions and properties of Laplace transform, continuous-time and discrete-time Fourier series, continuous-time and discrete-time Fourier Transform, DFT and FFT, z-transform. Sampling theorem. Linear Time-Invariant (LTI) Systems: definitions and properties; causality, stability, impulse response, convolution, poles and zeros, parallel and cascade structure, frequency response, group delay, phase delay. Signal transmission through LTI systems.

Control Systems: Basic control system components; block diagrammatic description, reduction of block diagrams. Open loop and closed loop (feedback) systems and stability analysis of these systems. Signal flow graphs and their use in determining transfer functions of systems; transient and steady state analysis of LTI control systems and frequency response. Tools and techniques for LTI control system analysis: root loci, Routh-Hurwitz criterion, Bode and Nyquist plots. Control system compensators: elements of lead and lag compensation, elements of Proportional-Integral-Derivative (PID) control. State variable representation and solution of state equation of LTI control systems.

Communications: Random signals and noise: probability, random variables, probability density function, autocorrelation, power spectral density. Analog communication systems: amplitude and angle modulation and demodulation systems, spectral analysis of these operations, **superheterodyne receivers**; elements of hardware, realizations of analog communication systems; signal-to-noise ratio (SNR) calculations for amplitude modulation (AM) and frequency modulation (FM) for low noise conditions. Fundamentals of information theory and channel capacity theorem. Digital communication systems: pulse code modulation (PCM), differential pulse code modulation (DPCM), digital modulation schemes: amplitude, phase and frequency shift keying schemes (ASK, PSK, FSK), matched filter receivers, bandwidth consideration and probability of error calculations for these schemes. Basics of TDMA, FDMA and CDMA and GSM.

Electromagnetics: Elements of vector calculus: divergence and curl; Gauss' and Stokes' theorems, Maxwell's equations: differential and integral forms. Wave equation, Poynting vector. Plane waves: propagation through various media; reflection and refraction; phase and group velocity; skin depth. Transmission lines: characteristic impedance; impedance transformation; Smith chart; impedance matching; S parameters, pulse excitation. Waveguides: modes in rectangular waveguides; boundary conditions; cut-off frequencies; dispersion relations. Basics of propagation in dielectric waveguide and optical fibers. Basics of Antennas: Dipole antennas; radiation pattern; antenna gain.

Electronics and Telecommunication Engineering Paper-I (For Both Objective and Conventional Type Papers)

1. Materials and Components

Structure and properties of Electrical Engineering materials; Conductors, Semiconductors and Insulators, magnetic, Ferroelectric, Piezoelectric, Ceramic, Optical and Super-conducting materials. Passive components and characteristics Resistors, Capacitors and Inductors; Ferrites, Quartz crystal Ceramic resonators, Electromagnetic and Electromechanical components.

2. Physical Electronics, Electron Devices and ICs

Electrons and holes in semiconductors, Carrier Statistics, Mechanism of current flow in a semiconductor, Hall effect; Junction theory; Different types of diodes and their characteristics; Bipolar Junction transistor; Field effect transistors; Power switching devices like SCRs, GTOs, power MOSFETs; Basics of ICs - bipolar, MOS and CMOS types; basic of Opto Electronics.

3. Signals and Systems

Classification of signals and systems; System modelling in terms of differential and difference equations; State variable representation; Fourier series; Fourier transforms and their application to system analysis; Laplace transforms and their application to system analysis; Convolution and superposition integrals and their applications; Z-transforms and their applications to the analysis and characterisation of discrete time systems; Random signals and probability, Correlation functions; Spectral density; Response of linear system to random inputs.

4. Network Theory

Network analysis techniques; Network theorems, transient response, steady state sinusoidal response; Network graphs and their applications in network analysis; Tellegen's theorem. Two port networks; Z, Y, h and transmission parameters. Combination of two ports, analysis of common two ports. Network functions: parts of network functions, obtaining a network function from a given part. Transmission criteria: delay and rise time, Elmore's and other definitions effect of cascading. Elements of network synthesis.

5. Electromagnetic Theory

Analysis of electrostatic and magnetostatic fields; Laplace's and Poisson's equations; Boundary value problems and their solutions; Maxwell's equations; application to wave propagation in bounded and unbounded media; Transmission lines: basic theory, standing waves, matching applications, microstrip lines; Basics of wave guides and resonators; Elements of antenna theory.

6. Electronic Measurements and instrumentation

Basic concepts, standards and error analysis; Measurements of basic electrical quantities and parameters; Electronic measuring instruments and their principles of working: analog and digital, comparison, characteristics, application. Transducers; Electronic measurements of non electrical quantities like temperature, pressure, humidity etc; basics of telemetry for industrial use.

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Electronics and Telecommunication Engineering Paper-II

(For Both Objective and Conventional Type Papers)

1. Analog Electronic Circuits

Transistor biasing and stabilization. Small signal analysis. Power amplifiers. Frequency response. Wide banding techniques. Feedback amplifiers. Tuned amplifiers. Oscillators. Rectifiers and power supplies. Op Amp, PLL, other linear integrated circuits and applications. Pulse shaping circuits and waveform generators.

2. Digital Electronic Circuits

Transistor as a switching element; Boolean algebra, simplification of Boolean functions, Karnaugh map and applications; IC Logic gates and their characteristics; IC logic families : DTL, TTL, ECL, NMOS, PMOS and CMOS gates and their comparison; Combinational logic Circuits; Half adder, Full adder; Digital comparator; Multiplexer Demultiplexer; ROM and their applications. Flip flops. R-S, J-K, D and T flip-flops; Different types of counters and registers Waveform generators. A/D and D/A converters. Semiconductor memories.

3. Control Systems

Transient and steady state response of control systems; Effect of feedback on stability and sensitivity; Root locus techniques; Frequency response analysis. Concepts of gain and phase margins: Constant-M and Constant-N Nichol's Chart; Approximation of transient response from Constant-N Nichol's Chart; Approximation of transient response from closed loop frequency response; Design of Control Systems, Compensators; Industrial controllers.

4. Communication Systems

Basic information theory; Modulation and detection in analogue and digital systems; Sampling and data reconstructions; Quantization & coding; Time division and frequency division multiplexing; Equalization; Optical Communication : in free space & fiber optic; Propagation of signals at HF, VHF, UHF and microwave frequency; Satellite Communication.

5. Microwave Engineering

Microwave Tubes and solid state devices, Microwave generation and amplifiers, Waveguides and other Microwave Components and Circuits, Microstrip circuits, Microwave Antennas, Microwave Measurements, Masers, lasers; Microwave propagation. Microwave Communication Systems terrestrial and Satellite based.

6. Computer Engineering

Number Systems. Data representation; Programming; Elements of a high level programming language PASCAL/C; Use of basic data structures; Fundamentals of computer architecture; Processor design; Control unit design; Memory organisation, I/o System Organisation. Microprocessors: Architecture and instruction set of Microprocessors 8085 and 8086, Assembly language Programming. Microprocessor Based system design: typical examples. Personal computers and their typical uses.

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JTO: Syllabus: Telecommunication Engineering

SECTION-I

1. Materials and components

Structure and properties of Electronic Engineering materials, Conductors, Semiconductors and Insulators, Magnetic, Ferroelectric, Piezoelectric, Ceramic, Optical and Superconducting materials. Passive components and characteristics, Resistors, Capacitors and Inductors; Ferrites, Quartz crystal, Ceramic resonators, Electromagnetic and Electromechanical components.

2. Physical Electronics, Electron Devices and Ics

Electrons and holes in semiconductors, Carrier Statistics, Mechanics of current flow in a semi-conductor, Hall effect; Junction theory; Different types of diodes and their characteristics; Bipolar Junction transistor; Field effect transistors; Power switching devices like SCRs, CTOs, power MOSFETs; Basics of ICs-bipolar, MOS and CMOS types; Basics of Opto Electronics.

3. Network theory

Network analysis techniques: Network theorem, transient and steady state sinusoidal response, and Transmission criteria: delay and rise time Elmore's and other definition, effect of cascading. Elements of network synthesis.

4. Electromagnetic Theory

Transmission lines: basic theory, standing waves, matching applications, micro strip lines; Basics of waveguides and resonators; Elements of antenna theory.

5. Electronic Measurements and Instrumentation

Basic concepts, standards and error analysis; Measurements of basic electrical quantities and parameters; Electronic measuring instruments and their principles of working: analog and digital, comparison, characteristics, and applications. Transducers; Electronic measurements of non-electrical quantities like temperature, pressure, humidity etc. Basics of telemetry for industrial use.

6. Power Electronics

Power Semiconductor devices, Thyristor, Power transistor, MOSFETs, Characteristics and operation. AC to DC converters; 1-Phase and 3-phase DC-to-DC Converters.

AC regulators. Thyristor controlled reactors, switched capacitor networks.

Inverters: Single-phase and 3-phase. Pulse width modulation. Sinusoidal modulation with uniform sampling. Switched mode power supplies.

SECTION-II

1. Analog Electronic Circuits

Transistor biasing and stabilization, Small Signal analysis. Power amplifiers. Frequency response, Wide band techniques, Feedback amplifiers. Tuned amplifiers. Oscillators. Rectifiers and power supplies. Operational Amplifier, other linear integrated circuits and applications. Pulse shaping circuits and waveform generators.

2. Digital Electronic Circuits

Transistor as a switching element; Boolean algebra, simplification of Boolean functions, Karnaugh Map and applications; IC Logic gates and their characteristics; IC logic families: DTL, TTL, ECL, NMOS, PMOS and CMOS gates and their comparison; Combinational logic circuits; Half adder, full adder; Digital Comparator; Multiplexer Demultiplexer; ROM and their applications. Flip-flops, R-S, J-K, D and T flip-flops; Different types of counters and registers; waveform generators. A/D and D/A convertors. Semiconductor memories.

3. Control Systems

Transient and steady state response of control systems; Effect of feedback on stability and sensitivity, Root locus techniques; Frequency response analysis. Concepts of gain and phase margins; Constant-M and Constant-N Nichol's Chart; Approximation of transient response from Constant-N Nichol's Chart; Approximation of transient response from closed loop frequency response; Design of Control Systems, Compensators; Industrial controllers.

4. Communication Systems

Basic information theory: Modulation and detection in analogue and digital systems; Sampling and data reconstruction. Quantization & Coding; Time division and frequency division multiplexing; Equalisation; Optical Communication: in free space & fiber optic; Propagation of signals at HF, VHF, UHF and microwave frequency; Satellite communication.

5. Microwave Engineering

Microwave Tubes and solid state devices, Microwave generation and amplifiers, Waveguides and other Microwave Components and Circuits, Microstrip circuits, Microwave antennas, Microwave Measurements, MASERS LASERS; Microwave Propagation. Microwave Communication Systems-terrestrial and satellite based.

6. Computer Engineering

Number Systems; Data representation; Programming; Elements of a high level programming language PASCAL/C; use of basic data structures; Fundamentals of computer architecture processor design; Control unit design; Memory organization. I/O System Organization. Personal computers and their typical uses.

7. Microprocessors

Microprocessor architecture - Instruction set and simple assembly language programming. Interfacing for memory and I/O. Applications of Microprocessors in Telecommunications and power system.

SECTION-III

General Ability Test

The candidate's comprehension and understanding of General English shall be tested through simple exercises. Questions on knowledge of current events and of such matter of everyday observation and experience in their scientific aspects as may be expected of an educated person. Questions will also be included on events and developments in Telecommunications, History of India and Geography. These will be of a nature, which can be answered without special study by an educated person.

About the Author

Satish K. Karna, ex-educational consultant, guided the Department of Electronics , Electrical and Computer Engineering. He runs Karna Institute of Engineering, Chandigarh . He has more than 15 years of experience in the engineering industries and teaching for competitive examinations (i.e., GATE / IES / PSUs). After graduation in Electronics and Communication Engineering, he obtained his M. Tech. in Computer Integrated Manufacturing from Punjab Engineering College, Chandigarh. His fields of interest are Communication Systems, Control Systems, Circuits Theory and Networks, Electronics Devices and Circuits, Analog Electronics, Digital Electronics. He has already written many text and reference books for competitive examinations.

1. ***GATE: Electronics and Communication Engineering*** by Satish K. Karna
2. ***GATE: Electrical Engineering*** by Satish K. Karna and Suman
3. ***GATE: Instrumentation Engineering*** by Satish K. Karna and Ravi Verma
4. ***Communication Systems (Theory / problems and solution / MCQs)*** by Satish K. Karna
5. ***Control Systems (Theory / problems and solution / MCQs)*** by Satish K. Karna
6. ***BSNL JTO: Question Bank with Detailed Solutions*** by Satish K. Karna
7. ***MTNL JTO: Question Bank with Detailed Solutions*** by Satish K. Karna
8. ***Electronics and communication for competitions*** by Satish K.Karna
9. ***Electrical for competitions*** by Satish K.Karna
10. ***Instrumentation for competitions*** by Satish K. Karna and Ravi Verma (in Press)
11. ***MCQ in Electronics and communication*** by Satish K.Karna (in Press)
12. ***MCQ in Electrical Engineering*** by Satish K. Karna (in Press)
13. ***GATE: Computer Science and IT*** by Satish K. Karna and Deepak (in Press)

PROPOSED BOOKS

1. Circuit Theory and Network (***Theory / problems and solution / MCQs***) by Satish K. Karna
2. Analog Electronics (***Theory / problems and solution / MCQs***) by Satish K. Karna
3. Signal and Systems (***Theory / problems and solution / MCQs***) by Satish K. Karna
4. Digital Electronics (***Theory / problems and solution / MCQs***) by Satish K. Karna

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MATERIALS AND COMPONENTS

1.1 STRUCTURE AND PROPERTIES OF ELECTRICAL ENGINEERING MATERIALS

Electronic Energies in an Atom of an Element

The electron bound to the nucleus of an atom can exist only in a series of energy states having sharply defined energies, (E_n). According to **Bohr's theory** of the atom

$$E_n = \frac{-2\pi^2 m_e e^4}{n^2 h^2} = \frac{-13.6}{n^2} \text{ eV};$$

(eV = electron volt)

As n increases, the E_n levels get closer, which states that no two electrons in bound state can have all the four quantum number n, l, m_l and m_s of the same magnitude and direction i.e., not more than two electrons can occupy the same energy level and these two must have opposite spins.

- *Principal quantum number (n)* which indicates the size of the orbiting electron (circular or elliptical). It is a measure of how the total energy is quantized.
- $n = 1, 2, 3, \dots, l = 0(s), 1(p), 2(d), 3(f), \dots, (n-1)$.
- *Azimuthal or Angular momentum quantum number (l)* which determines the elliptical motion of the electron orbit. It is the way in which the angular momentum is quantized.
- $l = 0, 1, \dots, (n-1)$.
- *Magnetic quantum number (m_l)* associates with orbiting electron in a plane, indicating its tiny magnetic behaviour. It is a measure of the angle between electron's angular momentum and an applied magnetic field.
- $m_l = 0, 1, \pm 2, \dots, \pm l; \quad m_s = \pm \left(\frac{1}{2}\right)$

- *Spin quantum number (m_s)* clockwise/anticlockwise.

- $m_s = +\frac{1}{2}, -\frac{1}{2}$

A solid in which the atoms are arranged in a regular periodic geometrical pattern, is known as a **Crystal** whose corner points form an **array** in space. This array of points is called a **Crystal lattice**. The spacing between atoms in a Crystal is the same for crystalline solid and is called the lattice constant d of the crystal.

Principles of Electron Energy Bands

When several atoms are brought together to form a solid crystal, each sharp level of the individual atoms, spreads into as many energy levels as there are atoms in the solid and yet Pauli's exclusion principle is not violated for electrons of the similar atoms in crystalline solid.

These energy levels are situated together very closely and thus form an energy band as shown in figure (1.1).

Electron Energy Band Scheme and Forbidden Bands

- The width of E-band depends on the corresponding E-level in free atom of the between atoms in the solid crystal which forms potential hills and well to control the flow of electrons across the crystal lattice.
- The lower energy levels are slightly affected by interaction between neighbouring atom and thus form very narrow bands.
- On the bands hand, the higher energy levels are affected very much by neighbouring atoms and expand into a wide band.

- The width of energy bands is greater if inter-atomic distance is less depending on the crystal lattice structure.
- The energy band structure of solids provides a basis which enables us to account for three distinct groups of crystalline solids viz.,
 1. Metals (good conductors)
 2. Insulators (bad conductors)
 3. Semiconductors

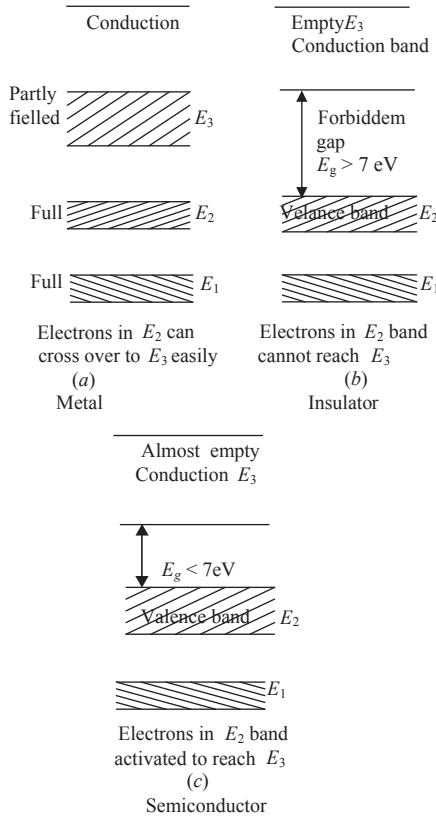


Fig. 1.1

Zone Model and Brillouin Zones

(Wave-Mechanics Model of Band Theory)

The outer or valence electrons which travel through the crystalline solid come across crystal lattice of the ions. The travelling electrons across the crystal lattice undergo **diffraction effects** in a periodic manner due to potential well and hills at the sites of positive ions of crystal atoms and valence-core electron cloud respectively. The average amplitude of the periodic potentials (hills and wells) corresponds to the width of energy gaps.

Electron wave of wavelength $\lambda = (h/mv)$ can be diffracted according to Bragg's diffraction law $n\lambda = 2d \sin \theta$.

Wave number

$$|K| = \frac{2\pi}{\lambda}$$

$$|K| = \frac{n\pi}{d \sin \theta}$$

The result indicates that there is at least one series of values of $|K|$ corresponding to integer n , for which electrons are diffracted and do not pass freely through the crystal. This statement should hold true whether the free electrons are part of an electron beam impinging on the crystal or an electron in the crystal (i.e., valence electron) or valence electrons in a crystal, these values of K correspond to the forbidden energies in the band structures.

n-type (Donor type) of semiconductor is Silicon or Germanium (both in IV group with covalent bond) doped with As or P of V group. The 5th electron of As or P in the host crystal to Si/Ge remains unengaged and it can be freed for conduction process since effective energy gap $= [0.1/10] \text{ eV} = E_D = 0.01 \text{ eV}$ as compared with $E_g = 1 \text{ eV}$ for intrinsic Si/Ge. Hence, n-type conductivity is $[1/0.10] = 100$ times more than that of pure Si/Ge.

This conductivity again increases with temperature very rapidly.

$$E_D = \left[\frac{1}{100} \right] E_i ; \sigma_n = \sigma_0 e^{-E_D/2KT}$$

p-type (Acceptor type) of semiconductor is Silicon or Germanium (both in IV group) doped with Boron or Gallium of III group. There is deficit of one electron in the host crystal which otherwise requires four electrons. In other words, electron-hole (*p*-type) is created. Its $E_g = 0.01 \text{ eV}$ just above the valence band.

$$\text{Net } E_A = E_g - \frac{1 \text{ eV}}{10} = \left(1 - \frac{0.01}{10} \right) = E_A$$

But this is an extra charge carrier and hence σ_A increases as compared to $\alpha_i \cdot \sigma_A$ again depends on temperature as per the equation.

$$E_A = \left(1 - \frac{0.01}{10} \right) = E_i = 0.9 E_i ; \sigma_A = \sigma_0 e^{-E_A/2KT}$$

Gallium Arsenide Versus Silicon

- Gallium Arsenide and other compound semiconductors (InP, ZnSe, AlGa Se, AlGaAs etc.) have the same average number of valence electrons per atom compared to silicon.
- In compound semiconductor the chemical bond between the nearest neighbours is **heteropolar**. However, in such compounds the bond is still more or less covalent. The compound semiconductors offer a variety of choices to a material scientist and a device designer. In spite of this Gallium Arsenide technology is the most developed compound semiconductor technology till date.
- Silicon and germanium are indirect gap semiconductors. Gallium arsenide and related compounds have several other advantages compared to silicon. The effective mass of electrons at the (*gamma*) minimum point is smaller than in X or L. This leads to higher electrons velocity.
- Hence GaAs devices are more suitable for high frequency/high speed application.
- Gallium Arsenide, being a **direct gap semiconductor** can be used to generate and detect both incoherent and coherent (laser) lights and hence is well suited for applications

in opto-electronics. The Gallium arsenide and Aluminum gallium arsenide are grown in layers one above the other for confinement of light. The recombination of holes and electrons in a direct gap semiconductor such as Gallium arsenide is more efficient. As a result, when Gallium arsenide is subjected to radiation, the electron-hole pairs produced by radiation recombine faster as compared to electron-hole pair produced by silicon. Hence GaAs devices are extensively used in circuits which operate satisfactorily in radiation environment.

Temperature Dependence of Materials

Conductors (Metal)

Electrical Resistivity with Temperature,

$$\rho = \frac{m^*}{Ne^2} \frac{1}{\tau}$$

The reciprocal of relaxation time $[1/\tau]$ represents the probability of electron suffering a scattering per unit time. Thus if $\tau = 10^{-14}$ sec, then the electron undergoes 10^{14} collisions in one second. This collision of electrons is due to two factors:

- Lattice Cross Vibrations (phonons) because of thermal excitation.
- Imperfection in the crystal (such as foreign atom or crystal defects).

$$\therefore \frac{1}{\tau} = \left(\frac{1}{\tau_{ph}} \right) + \left(\frac{1}{\tau_{imp}} \right)$$

1st term is due to Photon.

2nd term is due to Imperfection.

There are many free electrons in the crystal structure of a metal. Valence electrons are partly filled in the valence band and hence are free to move about.

Metal strip/write when connected to the external battery (voltage supply), allows the inherent ample free electrons to drift out into the external circuit and set up a current flow. Greater the external voltage, greater is the current according to *Ohm's Law* $I = [V/R]$.

$$\text{Electrical conductivity } \sigma = \frac{1}{R} = \frac{1}{V} = \frac{\pi r^2}{SL}$$

The thermal conductivity K is also high for metals. The ratio $[\sigma/K]$ = Electrical conductivity is a universal constant for all metals for a given temperature T . K , according to Wiedemann-Franz Law

$$[\sigma/K] = [T/L]$$

where,

L = Wiedemann-Franz constant.

It is to be noted that the electrical conductivity decreases with the rise in temperature of the metallic-conductor.

$$R_t = R_0(1 + \alpha t); \quad \sigma_t = \left[\frac{\sigma}{1 + \alpha t} \right]$$

Explanation for this effect (rise in R with temperature) is given later.

Thermoionic emission of electrons from metals and Photoelectric emission of electrons from metals give a practical illustration of the free-electron theory for metals, apart from good thermal and electrical conductivities for metal.

Thermistor

Thermistors are made from sintered mixtures of NiO , Mn_2O_3 , CO_2O_3 and have an exponential decrease in resistivity with temperature increase.

Hence they have negative temperature coefficient of resistance and can be used to compensate changes in circuit resistance which have positive temperature coefficient of resistance. Sometimes, heavily doped semiconductors have positive temperature coefficient $[dR/dt]$ and are called **sensistors**. They are also used as circuit elements.

Semiconductor

Because of the function of thermal energies, the free electrons and holes of a semiconductor move in random path. But, when an electric field is applied, motion of charge is called **drift** and can be described in terms of E -field and the conductor properties.

Current density (J)

$$= \text{Change density} = v = \rho v = -n e v_e$$

Semiconductor material vs Energy gap

C – Diamond $\rightarrow 7$ eV

Si – Silicon $\rightarrow 1$ eV

Ge – Germanium $\rightarrow 0.68$ eV

Sn – Tin $\rightarrow 0.08$ eV

But the conductivity σ of such semiconductors increases with rise in temperature, unlike metallic conductors.

$$\sigma_t = \sigma_0 e^{\left[\frac{-E_g}{2KT} \right]}$$

Insulators

In the case of bad conductor material, the forbidden energy gap E_g is so much wide $E_g > 20$ eV that there is no chance for electron in the valence band (fully occupied) to get excited by high thermal energy, to reach conduction band which is completely vacant. Not even a few electrons are available in top-conduction band even at 200°C in such a material called insulator.

1.2 CONDUCTORS

Ohm's Law for Metals

When an electric field is applied between two ends of a metallic bar, the localized kinetic electrons are forced to move along the metallic bar. Higher the electrical field gradient, greater is the velocity of electrons and larger are the electrons crossing unit area per second $I = (V/R)$.

Collision Time

It is defined as the average time interval between two successive collisions of an electron in a conductor.

Relaxation Time

The relaxation time is closely related to the mean time of flight between collision and also to the mean free path of the conduction electrons, which is the average distance of undisturbed motion between collisions. All the collision processes occurring in the electron gas can be explained through relaxation time. The collisions are caused by thermal or structure imperfection in the lattice. The relaxation time is introduced as the characteristic time governing the establishment of equilibrium through collision, from an initial disturbed situation in which $v_x \neq 0$.

Consider a conducting bar with electric field applied across its ends.

Let Electric field be removed at $t = 0$, then the drift velocity of electron for $t > 0$ is given by $v_d(t) = v_d(0) e^{-t/\tau_r}$.

Note: For isotropic materials, relaxation time is equal to collision time.

Mean Free Path

It is the average distance covered by an electron between two successive collisions, $\lambda_c = v_d \tau$.

The velocity and mean free path at Fermi level

$$W_F = \frac{1}{2} m V_F^2$$

mean free path $\lambda_F = v_F \tau_c$ and the probability that an e^- moves for time t without suffering a collision is given by $R(t) = e^{-t/\tau_c}$.

Joules Law

Heat developed in a conducting material, $P = I^2 R$

$$P = \frac{v^2}{R} = \frac{(E.l)^2}{(\rho l/A)} = \frac{E^2 l A}{\rho} = \sigma E^2 l A$$

Heat developed per unit volume

$$W = \frac{P}{lA} = \sigma E^2$$

$$W = \sigma E^2 ;$$

$$W = JE$$

Factors Affecting Conducting Property of the Conducting Materials

The resistivity of conducting materials according to *Mathissen's rule* is given by $\rho = \rho_{th} + \rho_r$

$\rho_{th} \rightarrow$ Thermal components (depends on temperature)

$\rho_r \rightarrow$ Residual resistivity (depends on impurity)

Note: So alloy of any material always has greater resistivity than the metal.

Factors Affecting the Resistivity of Metal

Temperature: The resistivity of conducting materials increases with increase in temperature T and it is given by $\rho = \rho_0 (1 + \alpha_1 (\Delta T) + \sigma_2 (\Delta T)^2 + \dots)$ where,

$$\Delta T \rightarrow T - T_o$$

$$T_o \rightarrow \text{Room temperature}$$

$$\rho_o \rightarrow \text{Resistivity at room temperature}$$

Note: The pure metal has zero resistivity at absolute zero.

Alloying: The alloys have less regular structure than pure metals. So the electrical conductivity of alloys is lesser than pure metals. Resistivity of alloy is given by $\rho_{\text{alloy}} = \rho_{\text{pure metal}} + S \rho_i$

$S \rightarrow$ Atomic per cent of impurity

$\rho_i \rightarrow$ Increase in resistivity per atomic per cent.

Cold working: The mechanical process produces localized strain which in turn decreases the conductivity of material.

Age hardening: If materials get hardened with age, their resistivity increases.

Materials	Conductivity
Insulator	$= 10^{-16} \text{ mho } m^{-1}$
Semiconductor	$= 10^{-2} \text{ mho } m^{-1}$
Conductor (Metals)	$= 10^8 \text{ mho } m^{-1}$

Conductivity of Pure Metals

$\sigma = ne\mu$ as temperature increases μ of electrons decreases due to thermal agitation which in turn results into decreased conductivity.

Note: At high temperature $\sigma \propto \frac{1}{T}$

At low temperature $\sigma \propto \frac{1}{T^5}$.

Increasing Order of Conductivity of Few Materials

$$K < Na < Al < Cu < Ag < An$$

The Conductivity of Alloys

In alloys, charge carriers are in saturation just like metals, therefore, conductivity depends upon carrier mobility.

When a metal is added with an impurity, the lattice potential becomes periodic and this leads to carrier scattering and increases the overall resistance of metal.

Nordheim's rule Specific resistivity of alloy

$$\rho_{\text{alloy}} = \beta x(1 - x)$$

where, $\beta \rightarrow$ constant

$x \rightarrow$ fractional part of impurity in metal.

When $x \rightarrow$ is very small, $1 - x \approx 1$

$$\rho_{\text{alloy}} = \rho_r = \beta x.$$

Matheson's Rule for Specific Resistivity

In pure metals and dilute alloys, the total resistivity ρ is the sum of two terms; thermal component, ρ_T , which arises from lattice vibrations, and the residual resistivity ρ_r caused by impurities and structural impurities therefore $\rho = \rho_T + \rho_r = [1/\sigma_e]$.

$\rho_r \rightarrow$ Residual resistivity and ρ_r exists even at absolute zero and total resistivity at any temperature is given by

$$\rho = \rho_{TH} + \rho_{res} \rightarrow \text{Mattheisen's Rule}$$

$$\rho_{TH} \rightarrow \text{Thermal component}$$

$$\rho_{res} : \beta x \rightarrow \text{Residual resistivity}$$

For a series of dilute Cu-Ni alloys, the residual resistivity increases as the nickel content of the alloy increases.

For pure metals, α the temperature-coefficient of resistivity, is about 0.004 per degree centigrade, while for alloys, α is generally lower.

Relation Between Temperature Coefficient of Alloys and Pure Metals

$$\alpha_{\text{alloy}} = \frac{\alpha_{\text{metal}}}{1 + \rho_{TH}}; \alpha_{\text{alloy}} < \alpha_{\text{metal}}.$$

Different Types of Electron Emission From Metals and Metallic Compounds

To cause direct emission of electrons from metals and metallic oxides, definite amount of energy should be supplied to the rather free electrons contained in solid metals.

Thermion Emission

Thermion Emission as per Richardson's Law

$$j_x = AT^2 e^{[-b/T]}.$$

When the energy is supplied to the electrons thermally (i.e., by heating the metallic filament or by passing current through it or by indirect heating of metallic oxide coating ring around the heated metallic wire), the electron emission is called **thermoionic**.

- But space charge due to electron-closed near the emitter, will present easy flow of electrons towards anode.
- If a biased grid is placed in the Einstein's equation

$$h\nu - h\nu_0 = eV_r = [1/2] mv^2.$$

Photoelectric Emission

Photoelectric emission is given by Einstein's equation

$$h\nu - h\nu_0 = eV_r = \left(\frac{1}{2}\right) mv^2$$

$h\nu = [hc/\lambda]$ equal to the energy of impinging photon of frequency ν , or wavelength λ on the metallic electrode coated with photo sensitive element cesium or sodium, $V_0 =$ threshold frequency of the incident photon. If $\nu > \nu_0$, the liberated electron will be emitted with a kinetic energy $KE = [1/2] mv^2$ and $V_r =$ retarding potential required to reduce the KE to zero.

Secondary Emission

Secondary emission of electrons is caused by bombardment of metallic plate by high energy electrons that strike the metallic surface. The bombarding particles transfer their energy to the electrons contained in metallic state.

Field Emission

Field Emission, a strong electric field near the surface of metal may be used to lower the potential energy barrier, space charge, existing at the surface. This type of emission is called Field Emission. There is appreciable increase in emission current from a heated cathode with increase in anode voltage. The effect is known as **Schottky effect** as given by the equation.

$$I = I_s e^{[0.44 \left(\sqrt{\frac{E}{T}}\right)]}$$

1.3 SEMICONDUCTORS

Intrinsic Semiconductors

Semiconducting materials are comparatively poor conductors of electricity. They are characterized by nearly full valence band, which is separated from nearby empty conduction band by a narrow energy gap of $E_g < 1.5 \text{ eV}$ or less, as per electronic energy band theory in earlier section.

The thermal energy can promote electrons to conduction band after breaking covalent bonds as in the case of Germanium and Silicon semiconductors. But the covalent bond is left with vacant **electronic-state** called electron-holes which can also serve as charge carriers by **drifting** process caused by applied electric field.

Both conduction electrons and holes serve as charge carriers intrinsically in the case of pure semiconducting materials like Ge and Si.

The electrical resistivity ρ of such an intrinsic semiconductor, varies with temperature T according to the relation.

$$\rho = A \cdot e^{[E_g/2KT]}$$

1.6 ■ Materials and Components

- Intrinsic semiconductor

$$T \uparrow \rightarrow \sigma \uparrow$$

∴ Increase in n is greater in comparison to decrease in mobility.

Extrinsic Semiconductors (p and n types)

The substitutional impurity atoms of higher or lower valence, $[Ge + P; Ge + Al]$ can contribute excess electrons to conduction band or holes to the valence band. Such composite materials are called **n -type** or **p -type** extrinsic semiconductors. The conductivity is increased many times since the resultant E_g is very much smaller with respect to E_g .

The mobility of a charge carrier is limited by collision with impurity atoms and photons (sound waves) inside the semiconductor materials. Excess carrier can be created by radiations and they can be neutralized at recombination center.

$$|e^- \leftrightarrow e^+| = E_R = h\nu = h[c/\lambda]$$

Extrinsic Semiconductor

Lower doping level

$$\sigma \propto T$$

$$\Rightarrow \sigma \uparrow \text{ with } T \uparrow$$

Higher doping level

$$\sigma \propto \frac{1}{T}$$

$$\sigma \downarrow \text{ with } T \downarrow$$

1. Normal doping level

As $T \uparrow \Rightarrow n \uparrow, \mu \downarrow$ and $n \uparrow > \mu \downarrow$

$$\therefore \sigma \uparrow$$

2. Bipolar → -ve temperature coefficient
MOSFET → +ve temperature coefficient
3. Sensistor → +ve temperature coefficient

$$\text{Unit of mobility: } \frac{m^2}{v - \text{sec}}$$

1.4 INSULATORS (DIELECTRIC MATERIALS)

Polarization

In dielectric materials, all electrons are bound; the only motion position in the presence of an electric field is a minute displacement of positive and negative charges in the opposite directions. The displacement is usually small as compared to atomic dimensions. A dielectric in which this charge displacement takes place is said to be polarized, and its molecules are said to possess induced dipole moments. These dipoles produce their own field, which adds to that of external field.

Polarization (P) is defined as dipole moment per unit volume

$$P = \frac{\text{Dipole moment}}{\text{Volume}}$$

$$= \frac{Qd}{V} \text{ (C/m}^2\text{)}.$$

Polarizability

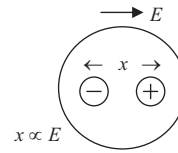


Fig. 1.2

$$\bar{P} \propto x; \bar{P} \propto \bar{E}$$

$$\bar{P} = \alpha \bar{E} \dots \alpha \rightarrow \text{Polarizability}$$

$$\alpha = \frac{P}{E} = \frac{Cm}{V/m} \text{ (Farad - metre}^2\text{)}.$$

Electronic Polarization, is defined as an electric strain produced in an atom due to the application of external field to the bulk material. It is the result of the displacement of the positively charged nucleus and the negative electrons of an atom in opposite directions.

Electronic polarization occurs in the materials in which there is no interaction between the different atoms or molecules of the materials.

Example: Inert gases, Diamond.

Expression for Electric Polarizability

The electronic **polarizability** of a material consisting of single type of atoms is given by $\alpha_e = 4\pi \epsilon_0 R^3$ where, $R \rightarrow$ Radius of atoms order of measuring α_e (60 H_2 to 10^{16} H_2)

$$\text{He} < \text{Ne} < \text{Ar} < \text{Kr} < \text{Xe} < \text{Rn}.$$

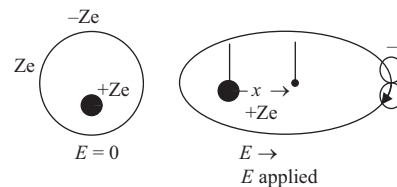


Fig. 1.3

$$\text{Atomic dipole of moment} = P_e$$

$$\text{Total dipole moment} = P = \sum_{n=1}^n P_{en}$$

Ionic Polarization is due to the displacement of cations and anions of a solid subjected to an external applied field up to 10^{13} H_2 .

This type of polarization occurs in the materials having ionic bonds.

Example: NaCl, HCl.

Such type of materials possess permanent dipole moment even in the absence of an external electric field.

When electric field is applied, the material will have two dipole moments.

One is due to electronic polarization and the other is due to induced polarization of the molecule as a hole.

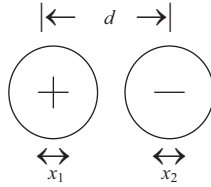


Fig. 1.4

Consequent resultant dipole moment (μ) per unit cell of the ionic crystal is given by $\mu = e(x_1 + x_2)$.

Molecular (Orientational) Polarization

When an electric field is applied on the dielectric medium with polar molecules, the localized moment vectors try to move along the direction of external electric field.

This type of polarization occurs in materials having partly ionic bond.

Example: H_2O , CO_2 , CH_3 , CHO .

CO_2 does not possess permanent dipole moment in the absence of an external field.

When an external field is applied, the material gets polarized.

Space-Charge (Interfacial) Polarization (P_j)

It occurs due to the accumulation of charges at the electrodes or at the interface in multiphase dielectrics as in ferrite and semiconductors.

Origin of Magnetism

1. **Diamagnetism** which is very weak, arises from changes in the atomic-electron orbital states as induced by the applied magnetic field.
2. **Paramagnetism** is the result of the presence of permanent atomic-electronic magnetic moments.
3. **Ferro magnetism** which is very strong, occurs when quantum-mechanical exchanges interactions can cause alignment of adjacent magnetic moments in the same direction forming domains.
4. **Antiferromagnetism** occurs when internal interactions of atomic magnetic moments align to opposite direction pairwise causing cancellation and neutralization of magnetism.
5. **Ferrimagnetism** is neither strong like ferromagnetism nor weak as in paramagnetism.

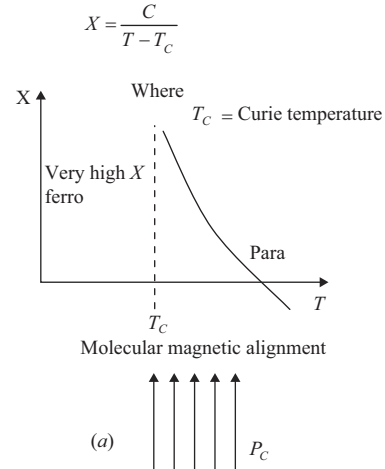


Fig. 1.5 Ferromagnetism

All vectors add up in the same direction. Thermal energy will reduce ferro to para above T_C .

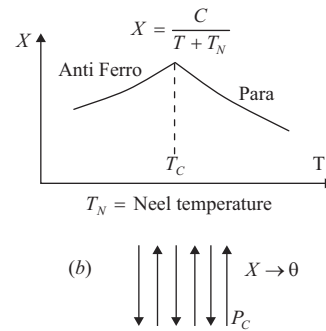


Fig. 1.6 Antiferromagnetism

Pairwise opposite vectors cause $X \rightarrow 0$. But thermal energy will disturb the neutrality, and X increases upto T_N point and then decreases due to thermal randomization of vectors.

Unequal pairwise vector cause X to be valid. $\bar{\mu} = (4M - 3m) > 0$. But thermal energy will cause randomization of vectors. Ferri becomes para.

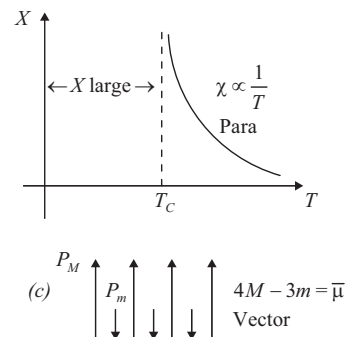


Fig. 1.7 Ferrimagnetism

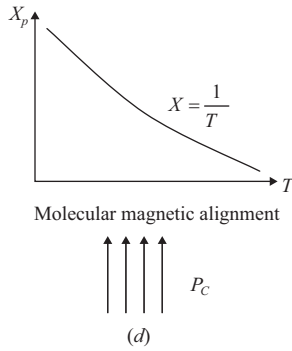


Fig. 1.8 Paramagnetism

1.5 MAGNETIC MATERIALS: CHARACTERISTIC

Magnetic Permeability

$$\mu = \frac{B}{H}, (H/m)$$

$\mu_o \rightarrow$ Permeability of free space i.e.,

$$\mu_o \rightarrow 4\pi \times 10^{-7} H/m$$

$\mu_r \rightarrow$ Relative permeability of a medium

Magnetic Dipole Moment

$$\vec{P}_m = \text{Current (Area of cross section of current loop)} \hat{n}$$

$\hat{n} \rightarrow$ Unit vector normal to the surface

$$\vec{P}_m = IA \hat{n}; \quad (A - m^2)$$

Magnetization

Magnetization is defined as magnetic dipole moment per unit volume

$$M = NP_m - (A/m)$$

Atomic Unit of Magnetic Moment-Bohr Magneton

$$\text{Bohr magneton} = \frac{e}{2m} \frac{h}{2\pi} Am^2$$

Relation Between Magnetic Flux Density and Magnetization

$$\vec{B} = \mu_o \vec{H} + \mu_o \vec{M}$$

$$\text{Also } \vec{B} = \mu H$$

$$\therefore \mu_o \vec{H} = \mu_o \vec{H} + \mu_o \vec{M}$$

$$\mu \vec{M} = \mu_o (\mu_r - 1) \vec{H}$$

$$\vec{M} = (\mu_r - 1) \vec{H}; \quad \vec{M} = \chi_m \vec{H}$$

where, $\chi_m = \mu_r - 1$

$\chi_m \rightarrow$ Magnetic susceptibility.

Diamagnetic Materials

Diamagnetic materials are composed of atoms that do not have any associated intrinsic magnetic moment but possess only weak induced magnetic moments.

Existence of diamagnetism is exhibited by rejection of H-line of external field. They are repelled by a magnet. Heating will destroy diamagnetism.

The diamagnetism arises due to circulating charge in orbits. Therefore all the materials exhibit diamagnetism

- The diamagnetic materials have -ve and very small magnetic susceptibility.
- The diamagnetic materials are repelled by the magnetic field.
- These materials move from higher intensity to lower intensity in magnetic fields.
- Magnetic susceptibility is independent of magnetic flux density and temperature.

Examples of Diamagnetic

Cu, Ag, Au, Al₂, O₃, diamond, Nickel.

Origin of Magnetic Dipole Moment

There are three mechanisms of angular momentum of charge in atoms which cause the magnetic dipole moments.

- Orbital angular momentum of electron
- Spin angular momentum of electron

Paramagnetic Materials

In paramagnetic materials like Mg, Al, V, Cr, Mo, W, the interaction between atoms having net spins is zero. The spins of the various atoms in the metal are randomly oriented and have a low net magnetization of about one-millionth (10^{-6}) that of ferromagnetic material. The low magnetism is again reduced as the temperature increases (because randomization of atomic magnets, causes zero residual magnetism).

In some materials, the permanent magnetic dipole moments of individual atoms are not acted upon each other. Therefore dipoles are randomly distributed and net magnetization of the material is zero. Such materials are called paramagnetic materials.

Note:

1. As temperature increases the thermal agitation among the individual dipole moments also increases.
2. When an external magnetic field is applied all the dipole moments get aligned in same direction parallel to each other. But with the increase in temperature thermal agitation causes disalignment of dipoles again.
3. Magnetic susceptibility of paramagnetic material is small and positive (10^{-3}).

4. Magnetic susceptibility of paramagnetic materials is more than diamagnetic materials.
5. Paramagnetic materials are attracted by the external magnetic field.
∴ These materials move from low intensity to high intensity of field.
6. Curie Law i.e., Variation of (X_m) paramagnetic $X = \frac{C}{T}$
7. Some paramagnetic materials follow Curie-Weiss Law

$$X_m = \frac{C}{T - \theta}$$

Example: Fe_2O_3 , MnSO_4 , FeSO_4 , NiSO_4 .

1.6 FERROMAGNETIC MATERIALS

Ferromagnetic Materials

Ferromagnetism involves an electrostatic interaction between adjacent atoms that affect the alignment of the resultant electron spins of the atom. *If the interaction is positive, the spins are aligned parallel to one another and their magnetic are additive and ferromagnetism results.*

The properties of ferromagnetic element are explained on the basis of existence of domains of atomic magnet with the resultant magnetic moment vector which is different for different domains in Helter-Skelter directions. These domain vectors undergo orientation towards the direction of applied field. Magnetization increases with the strength of applied field.

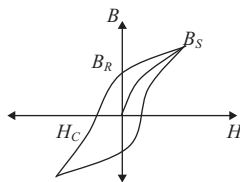


Fig. 1.9 (a)

B_s = Saturation value

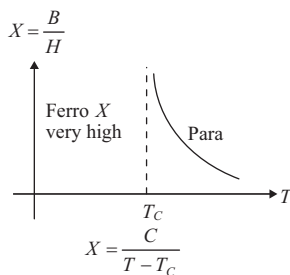


Fig. 1.9 (b)

Due to large Hysteresis loss of energy, ferromagnetic cores (for transformer action) cannot be used for frequencies above 4 kHz. It is ferrite core which can be used for high frequencies from 10 kHz to 10 MHz, etc.

- Ferromagnetic materials have all the dipole moment aligned parallel to each other even in the absence of external magnetic field.
- The magnetic susceptibility of ferromagnetic materials is positive and very large.
- These materials consist of the elements with partly filled inner electron cells.
- The Iron group is an example of Ferromagnetic materials.

The Ferromagnetic materials exhibit spontaneous magnetization only upto a critical temperature called curie temperature. These materials behave paramagnetic materials above the Curie temperature and follow Curie-Weiss Law $\lambda_m = \frac{C}{T - \theta}$.

Example: Co, Fe, Ni, Gd, Dy.

Ferromagnetic materials are oxides of metals with iron like MoFe_2O_3 , where, M is a bivalent metal i.e., Fe, Cu, Mn, etc., whose structure is of the spinel family.

A spinel like $(\text{MgAl}_2\text{O}_4)$ is a compound whose Al (trivalent) atoms and Mg atoms occupy tetrahedral sites in an FCC oxygen lattice. (Other trivalent and divalent metal iron may be used in place of Al and Mg).

Curie temperature of these materials is given by

Co	→	1393
Fe	→	1043
Ni	→	631
Gd	→	289
Dy	→	105

Behaviour of Ferromagnetic Materials Below Curie Temperature

Magnetic susceptibility of ferromagnetic materials increases with increase in temperature, for temperature less than curie temperature.

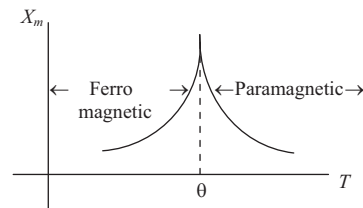


Fig. 1.10

The materials exhibit $B-H$ curve at temperature below Curie temperature.

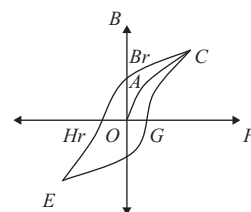


Fig. 1.11

When a fresh ferromagnetic is subjected to external magnetic field, it follows OAC of the BH curve as shown in the figure.

When the external magnetic field is removed, the materials remain magnetized permanently and this remaining magnetic flux density is called “Residual Magnetism”

Coercive Field

The magnetic field required to be applied continuously in opposite direction to reduce the resident magnetism to zero.

Spontaneous Magnetization

Below the curie temperature, a ferromagnetic material remains magnetized permanently even if external applied field is removed.

The property of ferromagnetic materials is called spontaneous magnetization.

Spontaneous Magnetization

$$M_r = \frac{B_r}{\mu_0}$$

where, $B_r \rightarrow$ Residual magnetic flux density.

Behaviour of Ferromagnetic Materials Above Curie Temperature

As the temperature increases above the curie temperature, the internal field of the material is not sufficient to maintain the parallel alignment of magnetic dipole moments that are randomly distributed above Curie temperature and materials behave like paramagnetic materials.

Above the curie temperature, the materials follow Curie-Weiss law

$$X_m = \frac{C}{T - \theta}$$

Note: Molecular field is mainly responsible for alignment of dipoles in one direction.

Ferro Magnetic Materials

The ferromagnetic materials in demagnetized state are divided into a number of small regions, the dipole moments in each of these regions are aligned in the same direction but the direction of alignment varies from one region to another. These regions are called “Ferromagnetic Domains” and wall separating “Ferromagnetic Domains” is called “Domains Wall”.

Note: Material used in transformer should have low Hysteresis and high permeability.

Ferroelectric Material

When a Ferro electrical material is subjected to external field it gets polarized and it remains polarized even when the external field is removed. The direction of polarization can be changed by applying external field in the opposite direction. The Ferroelectric material exhibits spontaneous polarization. When a fresh

material is subjected to external electric field, it follows the path OAC of Hysteresis characteristic as shown below:

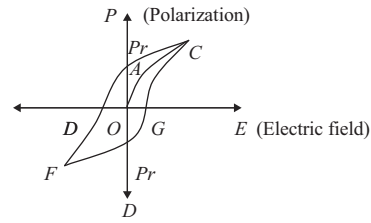


Fig. 1.12

When external electric field is removed, the material retain some polarization as shown in figure. This polarization is called *residual polarization*, where, $P_r \rightarrow$ Residual polarization.

Coercive Field

This is the electric field required to be applied in opposite direction to reduce the residual polarization to zero. The Ferroelectric material exhibits spontaneous polarization only upto a critical temperature called the curie temperature.

After curie temperature, the material stops behaving like ferroelectric material and it starts behaving like piezo-electric material.

Notes: Above curie temperature, the Hysteresis loop merges into a straight line.

Condition for Spontaneous Polarization

$$\frac{N\alpha\gamma}{\epsilon_0} = 1$$

Expression for Curie-Weiss Law

The ferroelectric materials above the Curie temperature follow a law called Curie-Weiss law.

Polarization of materials change with temperature hence orientational polarization and it is given by

$$\bar{P} = N \bar{E}_i \alpha_o; \quad \bar{P} = \frac{N P_p^2}{3 K T} E_i$$

$$\epsilon_r - 1 = \frac{C}{T - \theta}$$

Note:

1. In case of ferroelectric material, relative dielectric constant increases with increase in temperature when temperature of material is less than curie temperature.
2. In Ferroelectric material, polarization is not a unique function of the electric field.

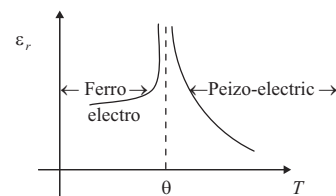


Fig. 1.13

Examples of Ferroelectric Materials

1. BaTiO₃.
2. CaTiO₃.
3. PbTiO₃.
4. Rochelle's salt.
5. Potassium dihydrogen phosphate (KDP).
6. Ammonium dihydrogen phosphate (ADP).
7. Lead Zirconate (Pb₂RO₃).

Note: All the ferroelectric materials are pyroelectric.

All the pyroelectric materials are Piezoelectric but reverse is not true.

Anti Ferroelectric Materials

- These are the materials which do not possess permanent dipoles moment because of geometry of spontaneous polarization.
- The neighbouring dipoles are aligned in antiparallel to each other.
- The antiferroelectric materials lose their antiferroelectric property above a critical temperature called curie temperature.

1.7 PIEZOELECTRIC MATERIALS

Piezoelectric Materials

When a material gets electrically polarized if it is subjected to mechanical stress and it also gets strained when subjected to electric field, the material is called *piezoelectric material*.

Strain produced in the material when subjected to electric field is proportional to the field applied i.e., strain $\propto E$.

Direct Effect

The application of mechanical stress produces a strain which in turn polarize the material.

Inverse Effect

The application of electric field produces the strain.

These are both linear effects. Such materials obey the following equations:

$$T = cS ; \quad S = sT ; \quad P = dT$$

A stress T results in a strain S in a material and c is an elastic stiffness constant; s is reverse of c . The stress T will produce a polarization; d is called piezoelectric strain constant.

The dielectric displacement, in the presence of stress is given by $D = \epsilon E + d T$ and the inverse effect is given by the relation

$$S = sT + d E$$

As most of the crystalline are anisotropic, these relations are mostly complicated, and that electric or mechanical force applied in one direction may produce effect in other directions. Tensor notations should be used in above equation.

Electrostriction

When a material gets strained when subjected to an electric field reverse effect is not observed. The property of such material is called electrostriction. The strain in such materials is proportional to square of electric field applied i.e., strain $\propto E^2$.

Note: In Electrostriction there is only inverse effect.

Pyroelectric Materials

These are the materials which possesses spontaneous polarization even in the absence of external electric field.

The polarization of the material changes with temperature and change in the polarization is given by

$$\Delta P = \lambda \Delta T$$

where, $\Delta T \rightarrow$ Change in temperature

$\lambda \rightarrow$ Pyroelectrical coefficient.

1.8 CERAMIC MATERIAL

- A ceramic is a compound formed by the combination of metallic and nonmetallic elements. Hence metal oxides, carbides, nitrides, borides and silicates are considered as ceramics.
- Examples refractive, glasses, abrasive, enamel, insulating materials etc.
- Ceramic materials are characterized by the presence of one type of bond in a single material. Due to presence of strong ionic and covalent bond ceramics possess high hardness, brittleness, high melting point, chemical inertness and electrical insulation.
- Ceramic are clay products sintered and fused at temperature of about 1500°C. Their main characteristics are low water absorption, low thermal expansion and good electrical properties. They cannot be machined but only molded.

Types of ceramic used in electrical engineering:

- Porcelain:** It is commonly used form of ceramic for LV and HV applications. Its composition is
 1. Clays–Kaolin (China clay) Al₂O₃, 2SiO₂, 2H₂O.
 2. Filter agents–Quartz SiO₂.
 3. Fluxing agents–Feldspar, pegmalite.
 4. Glaze producing agents.
- Chalk dolomite clays give plasticity and make the material suitable for molding. Quartz reduces shrinkage, deformation and prevents cracking during firing. Fluxing agent reduces the firing temperature.
- Porcelain is used as insulator in transmission and distribution lines, transformer bushings, fuse links, plugs and sockets.
- Stealite:** It is made from talc hydrated magnesium mixed with small quantities of clay and field spar. It has better electrical properties and used in hf applications. It is very hard, tough, mechanically strong material. Its good electrical properties are retained even at high temperature.

- (c) **Alumina:** It is made from aluminum oxide (Al_2O_3) and used in vacuum tubes and furnace as it can withstand 20 times greater temperature than porcelain.
- (d) **Titanite:** This is made from metal oxides and titanium dioxide. Barium titanite has very high dielectric constant and positive temperature coefficient of resistance. It is used in phonograph pickup, accelerometers.

Ceramics are affected by

1. **Temperature:** Its electrical resistance decreases with temperature.
2. **Moisture:** Though they are not affected by moisture, moisture penetration is prevented by glazing which also helps in preventing dust and dirt formation on the surface.

Cermets

Cermets are composite materials consisting of combination of metals and ceramics. They are used as resistors.

Types:

- (a) Metals + oxide ceramics with Fe, Cr and tungsten.
- (b) Metals + carbide ceramics with Fe, Ni and Co.

The metal acts as a binder. Cermets are made by powder metallurgy with sintering temperature above the melting point of metal powder. In the finished cermets, the metal contributes high toughness and thermal shock resistance, while the ceramic contributes to higher refractory properties creep resistance, superior chemical stability and abrasion resistance.

1.9 OPTICAL MATERIAL

There are two types of optical materials, one is glass and the other is semiconductor material which cause diffusion of electrons and holes on excitation by light of particular frequency.

In electrical engineering, the glass that is widely used is quartz or silica glass.

Optical lenses have the added purpose of refracting the light along an optical path. The index of refraction, which is a property of the material is a second factor in lenses specification and must be considered in all optical systems.

Indices of Refraction

The indices of refraction, n , of material is the light velocity in a vacuum, v_o to the velocity in that material, v_m ; $n = \frac{v_o}{v_m}$

When light is passed from one material to another, the ray is refracted according to *Snell's law*. When we incorporate that law with equation

$$\frac{n_1}{n_2} = \frac{v_1}{v_2} = \frac{\sin \phi_2}{\sin \phi_1}$$

with the angles and refraction being those of figure.

Electronic polarization is operative at light frequencies (10^{15} Hz), the relationship is between the index, n , and the electronic dielectric constant K_e :

$$n = \sqrt{K_e}$$

The value of this dielectric constant depends on the number of electrons that are encountered per unit length and their polarizability. There are two consequences of this relationship. First a denser phase of a given material has larger indices of refraction. Thus, in Table, quartz $\rho = 2.65 \text{ g/cm}^3$ shows a therefore, the change in the indices is a function of $\rho^{-1/3}$. Second, in non-cubic materials, the electronic polarization varies with the direction of light vibration. Thus, the indices of refraction is anisotropic. For example, calcite (CaCO_3) has its $(\text{CO}_3)^{2-}$ ions oriented such that the four atoms lie in the (0001) plane of the hexagonal crystal. The electronic polarization is 24 percent greater for light vibrating in the plane (A), which is perpendicular to the vertical axis, than for light vibration in the plane parallel to the vertical axis (B). This produces two indices of refraction –1.66 and 1.49, respectively. This difference is called *birefringence* and appears as *double refraction*. Glasses and materials with cubic crystal do not have birefringence because the electronic polarization is isotropic.

The electronic polarization increases slightly with frequency, therefore, the indices of refraction also increases with frequency. The spread in indices between blue and red is called dispersion. The shorter wavelengths have higher indices (slower velocities). This is of importance in lens system where it is mandatory that all colours have the same plane of focus. It also means that different colours of light will get out of phase as they travel through optical waveguides. The indices for a few selected materials. Two wavelength (yellow and red) are included for two optical and for fuses silica (used for optical fibers). The high indices and dispersion of diamond produces its “brilliance”.

1.10 SUPERCONDUCTIVITY

The resistance of a metallic conductor, decreases with decrease in temperature. But it cannot be zero at 0 K. There is a residual resistance even at 0 K. But there are some pure metals like niobium, hafnium, which become superconductors at very low temperature. When an electric current is induced in such superconductors, a large current (60 A) will flow out in the circuit for few days. So superconductivity gives promise of reducing line losses in transmission of electricity from power stations to consuming centers.

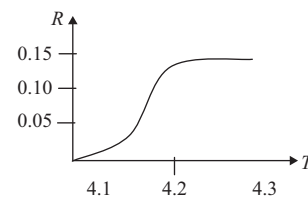


Fig. 1.14 The resistance of mercury as a function of temperature

The stage of material at which resistivity reduces to zero is called superconductivity. At this stage, the energy gap of

superconductor is minimum at critical temperature. The Hg is first ever discovered superconducting material with transition temperature equal to 4.2°K.

Transition Temperature

It is the temperature at which there is transition from normal state to superconducting state.

The transition temperature of superconductor can be reduced by the application of a magnetic field. With reference to figure, suppose a superconductor has a temperature $T < T_c$. If a magnetic field H_s applied, the material remains superconducting until a critical field H_c is reached such that for $H > H_c$, the material is in the normal state. The curve in figure represents schematically the function relationship between the critical field H_c and the temperature of the superconductor. The transition from the superconducting to the normal state under influence of a magnetic field is reversible. The function $H_c(T)$ follows with good accuracy a formula of the form

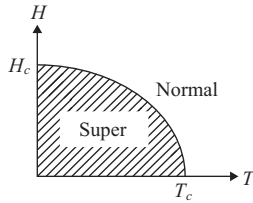


Fig. 1.15 Schematic representation of the critical magnetic field H as a function of temperature

$$H_c(T) = H_o \left(1 - \frac{T^2}{T_c^2} \right)$$

where, H_o and T_c are constants characteristic of the material.

Effect of Magnetic Field on Superconductivity

The superconducting materials lose their superconductivity when magnetic field around its surface exceeds a critical value.

The critical field at any temperature T is given by

$$H_c(T) = H_o \left(1 - \frac{T^2}{T_c^2} \right)$$

$H_o \rightarrow$ Critical field at (°K)

$T_c \rightarrow$ Transition temperature °K.

Thermodynamic

The main thermodynamic property is that at the critical magnetic field, the free energies, the normal and superconducting state must be equal for two-phase equilibrium.

Note:

1. The materials having highest transition temperature with $T_c = 23.2^\circ\text{K}$ is Nb_3Ge .

2. The compounds which are commonly used superconductors are Nb-Ti, Nb_3Sn , V_3Ge .
3. The elements which become superconductor are

1. Be	2. Zn	3. Cd
4. Hg	5. Al	6. Ge
7. Sn.		

Silsbee Effect

The magnetic field around the superconductor may not necessarily be external field, it can be self induced field of the conductor and the induced field on the surface of a conductor carrying current I is given by

$$H = \frac{I}{2\pi R}$$

where, $R \rightarrow$ Radius of conductor

$$I = 2\pi R H$$

When $H = H_c$ Then $I = I_c = 2\pi R H_c$

According to Silsbee rule, material is superconductor only for $I < I_c$

$$I = I_c = 2\pi R H_c$$

Meissner's Effect

According to Meissner's effect, the magnetic flux density in conductor at superconductivity state is zero. Magnetic flux density inside a material

$$\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{M}$$

At superconducting state,

$$\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{M} = 0$$

$$\Rightarrow \mu_0 \vec{H} = -\mu_0 \vec{M}$$

$$\frac{H}{M} = -1 = X_m$$

Note:

1. The (X_m) of material at superconducting state is negative and unity.
2. This refers to perfect Diamagnetism and this phenomena is called Meissner's effect.
3. The zero resistivity.
4. Perfect diamagnetism are two independent conditions for a material to be superconductor.

Effect of Frequency

Superconducting behaviour observed only for dc or slowly varying current. As the frequency increases, the resistance of material increases due to skin effect the superconductivity is observed only from dc to radio frequencies. At infrared frequencies (10^{13} Hz), the ρ at superconductivity state is same as that of normal state.

Effect of Superconductivity on Entropy of Material

The entropy increases as the matter changes its state from superconducting to normal state.

Application of superconductor:

1. Used to produce strong magnetic fields.
2. Used for the winding of transformer
3. Materials used for strong magnetic field are: Nb₃ Sn, Nb (25% Zr), Nb (44% Ti).
4. Used for design of modulators rectifiers, used for detection of modulated high frequency waves.
5. Used for the winding of exciting field of generators of low rating.
6. Used in the electrical switching elements called *cryotrons*, the switch used can be
 - (a) Temperature controlled
 - (b) Magnetically operated current switch

1.11 RESISTOR

The resistive properties of a number of metals and alloys are practically applied in the manufacture of resistance, precision electrical resistors and heating elements. The temperature coefficient of resistivity of pure annealed Pt is used to define the high-temperature scale between the melting points of pure elements. Cu and Ni are also used for resistance thermometers.

For precision resistors in electronic, a very small temperature coefficient of resistivity in the vicinity of room temperature is normally desired. Manganin (83% Cu, 13% Mn, 4% Ni), Constantan (55% Cu, 45% Ni), or a 72% Fe, 23% Cr, 5% Al, 0.5% Co alloys are used in a stress-relieved condition for this purpose. These alloys are metallurgically stable, corrosion resistant, and show a temperature coefficient per $\alpha < \pm 20 \times 10^{-8}/^{\circ}\text{C}$ between 0°C and 100°C .

For heating-element application, the oxidation resistance of the material is more important than in electrical. Although it is very expensive. Pt is sometimes used at high-temperature furnace winding. More commonly, resistance elements are made nichrome (80 Ni, 20 Cr) or, for higher temperatures, 55 Fe, 37 Cr, 8 Al alloy. The semiconductor silicon carbide and molybdenum disilicide can be used as heating elements at higher temperatures. Oxidation resistance in these materials is insured by the silicon dioxide film which forms on the surface at elevated temperatures. To achieve even higher temperatures by resistive heating requires the use of W, graphite, or Ta elements W and graphite may be employed in reducing atmosphere, but Ta only in a vacuum.

Magneto Resistance and Relation to Hall Effect

Hall effect transforms an input current i into an open circuit output, voltage v , due to transverse magnetic field acting on a semiconductor.

The ratio $[v/i] = R_H$ resistance due to Magnetic Field effect.

R'_H is known as magneto-resistance as against electrical resistance.

If Hall coefficient R_H is very high for a semiconductor, R'_H is also high.

$$\Delta' R_H = r B^2 \propto H^2.$$

1.12 FERRITES (FERRIMAGNETIC MATERIALS)

Special Characteristic of Ferrites

In Ferrites, nearly all of the valence electrons are tied up in bonds with neighbouring atoms. Thus their conductivity is less and hence *unable to generate Eddy Current* (unlike ferro-metals) and also damper mechanical and electrical vibrations. The only thing is that ferrites have weak magnetic moments [1/4] of ferromagnetic materials. But ferrites have Hysteresis loops very much rectangular in shape i.e., large saturation magnetization. Hence they are very much suited for core materials for high frequency transformers.

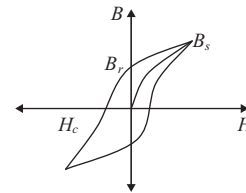


Fig. 1.16

Figure 1.16 shows small loop area of ferrimagnetic materials. Switch rate is fast as required for high frequency applications.

Curie-Weiss Law for Ferromagnetism

$$\text{Magnetic susceptibility, } X = \frac{M}{H} = \frac{C}{T - \theta}$$

This is termed as Curie-Weiss law.

Curie law alone indicates that below Curie temperature ($T < \theta$), X becomes negative (i.e., para-magnetic would become diamagnetic). But for most paramagnetic, Curie temperature is very low and $T < \theta$ situation can rarely arise.

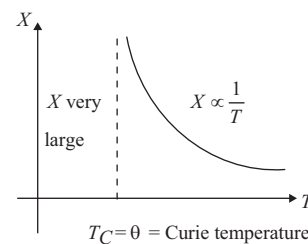


Fig. 1.17 Ferromagnetic behaviour with temperature

- The dipole moments in these materials are aligned in antiparallel but net magnetization is not zero and therefore materials possess a net magnetic moment. This net magnetization disappears above a critical temperature called “Curie temperature”.
- The Ferrimagnetic materials have *high dc resistivity* and hence these materials are preferred for construction of magnetic core at microwave and high frequencies. At these frequencies, the eddy current losses in ferrites are lower than the ferromagnetic materials.

Note: Resistivity of ferrites are more than Ferromagnetic materials.

Electric and Magnetic Characteristic of Ferrites

1. High resistivity
2. Low dielectric losses
3. High permeability
4. High curie temperature
5. Mechanically hard and Brittle.

Application of Ferrites

1. For permanent magnets, these ferrites are called Hard Ferrites and have high resistivity and high coercive force.
Example: Barium and strontium ferrites. These ferrites have high uniaxial anisotropy.
2. For transformer and inductor cores, these are called soft ferrites. These ferrites have, high permeability, low coercive force, low eddy current losses and are able to operate up to 10 MHz
Example: Mn, Zn, NiZn.
3. For data storage: The ferrites having rectangular Hysteresis loop that can be used for construction of magnetic memory core.
Example: Mn-Mg, Mn-Cu, Li-Ni Ferrites.
4. For Microwave component: At microwave frequencies, 1 to 100 GHz, the E.M. waves interact with spin magnetic moments of materials, and the process which takes place is called Faraday's Rotation.
Example: $\text{Mn Fe}_2 \text{O}_4$, $\text{Ni Fe}_2 \text{O}_4$, $\text{Co Fe}_2 \text{O}_4$.

Soft Magnetic Materials

The magnetic materials in which direction of magnetization can be altered easily by an applied magnetic field are called, soft magnetic materials. Such materials have *high permeability*, low coercive force, low Hysteresis and eddy current loss.

Applications

These materials are used as core of the transformer machines and magnetic memory core.

Example: Alloys of iron, Ni-Fe Alloy with 30–80% Ni, Ferrites, Iron with silicon, Si, 4–5% content is used for construction of

transformer core, used at low frequencies. Iron with nickel contents is used for high frequencies. Ferrites can also be used at high frequencies.

Soft Materials	Application
1. Silicon Steel	Used for transformer core construction with 4% content of silicon With (3, 5–4.5)% content steel can be used with large alternators and rotating m/cs
2. Fe-Co alloy Fe-49% Co- 49% V- 2%	Servomotor (core) loudspeaker telephone diaphragms magnetic pole tips
3. Ni-Fe alloy (a) Ni (36%) (b) Ni 50% (c) Ni (77%)	High speed relays and wide band transformers Magnetic memory, pulse transformer, inverters Recording heads, sensitive relays used for magnetic shielding

Hard Magnetic Materials

- Hard magnetic materials retain a considerable amount of magnetic energy after the magnetizing force has been removed.
- These materials are difficult to demagnetise, such materials are also called *permanent magnetic materials*.

Characteristics of Hard Magnetic Materials

1. Low permeability
2. High curie temperature
3. High coercive force
4. Good residual magnetism

Hard magnetic materials	Uses
Carbon Steel	Magnets of toys, compass Needle, latching relays, metre
Tungsten Steel	Used for dc motor magnets

1.13 QUARTZ CRYSTAL

Quartz crystal (SiO_2) also are piezoelectric. They are produced for special application in circuits requiring frequency control. Once they are cut to a selected geometry, the elastic vibrational frequency is constant to one part in 10^8 . Thus, in resonance, the crystal can control the frequency of an electronic circuit to that some precision. Fine watch circuit and control for radio broadcasting are two applications that use the piezoelectric characteristics of quartz crystal.

1.14 ELECTROMAGNETIC COMPONENTS

Power Transformer

The core material should be a ferromagnetic material with high susceptibility but the hysteresis loop area should be small. This can be achieved by using lamina layers or iron plates kept one above the other separated by insulating paint or insulating material. 60 Hz means there are 60 cycles of magnetization and $[1/60]$ sec per cycle is adequate for Fe to restore its magnetism to produce.

AF Transformer

AF transformer, for core Nickel 45%, iron 55% (Perm alloys) must be used, because the associated hysteresis loss is very much small with respect to ferro-material for each cycle time.

$$= \frac{1}{20 \times 10^3} = 0.2 \times 10^{-3} \text{ sec}$$

Laminar core reduces eddy current loss.

Radio-frequency Transformer Core, Ferrites

For **Radio-frequency transformer core**, ferrites are used because of low hysteresis loss. Eddy current are very small due to high resistance of ferrites ($10^{11} \Omega$).

Pulse Transformer Core, Ferrox Cube

For **Pulse Transformer core**, **Ferrox cube (50% MgO + 50% MnO) $\text{Fe}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$** ferrite material is used since they can respond fast to current pulses because the switching time can be as small (10^{-6} sec) as corresponding MHz range.

Microwave Devices, Garnets

For use in **Microwave devices**, **Garnets** (ferro-magnetic) like ferrites with general formula $\text{M}_3\text{Fe}_5\text{O}_{12}$, are used. They are having high resistance, small hysteresis loss and small eddy current loss.

Magnetic Shielding

Magnetic shielding is possible if we use mu-metals which have higher permeability, lower hysteretic loss, low eddy current. This isolate external H-field is influenced so that internal electromagnetic instrument action can be ensured for intrinsic operation. (mu-metal: 75% Ni + 5% Cu + 2% + 18% Fe) will $\mu\tau = 30,000$.

Soft Magnetic Materials

A material which can be magnetized easily, is called a soft magnet. If the magnetic domain walls are easy to move, they are aligned in the direction of applied magnetic.

If it is difficult to move the domain walls and coercive force is large, the material is magnetically hard.

Soft magnetic materials are processed to have maximum permeability (μ_r high) low B - H loop area and low eddy current losses.

Magnetic Anisotropy

In single crystal materials such as Fe, the magnetic properties depend on the direction in which they are induced. Such materials are called magnetic anisotropic materials and phenomena is called magnetic anisotropy. Magnetic anisotropy can be induced in the material by some mechanical operations. Such as *cold working*.

Methods of Inducing Uniaxial Anisotropy

1. Cold working: such as cold rolling mill.
2. Magnetic Annealing: Heat treatment of magnetic material in a magnetic field induces a uniaxial anisotropy.
3. Magnetic quenching: The material is cooled in the presence of a magnetic field through curie temperature this leads to uniaxial anisotropy.

Magnetostriction

When a magnetic material is magnetized, changes in physical dimension occur in the materials, this phenomena is called magnetostriction.

Types of Manetostriction

1. **Longitudinal manetostriction:** When the change in dimensions are in the direction of magnetization, the magnetostriction is called longitudinal.
2. **Transverse magnet striction:** If change in dimensions are perpendicular to the direction of magnetization, the magnetostriction is called Transverse magnetostriction.
3. **Volume magnetostriction:** If there is change in dimension both in perpendicular and parallel to the magnetization, the magnetostriction is called volume manetostrications.

Joule's Magnetostriction

The longitudinal magnetostriction is also called joule's magnetostriction and it is generally.

$$\lambda = \frac{\Delta l}{l}$$

Note: Ni, Co.

→ contracts when exposed to magnetic field in either direction.
Ni-Fe alloy → expands when it is magnetized

The Fe crystal → expands when it is magnetized in easy direction of magnetization and contract when magnetized in hard direction.

Villari Effect

It is converse of magnetostriction effect. The deformation of the material leads to changes in permeability of the material in the direction of applied strain

$$(a) +\lambda \begin{cases} +ve \text{ strain} \rightarrow \mu \uparrow \\ -ve \text{ strain} \rightarrow \mu \downarrow \end{cases}$$

$$(b) -\lambda \begin{cases} +ve \text{ strain} \rightarrow \mu \downarrow \\ -ve \text{ strain} \rightarrow \mu \uparrow \end{cases}$$

Application of magnetostriction

1. It is used for underwater sound detectors.
2. For generation of super sound.
3. For high frequency oscillations.

Antiferromagnetism

- Antiferromagnetic materials have small but positive magnetic susceptibility.
- The magnetic dipole moments in these materials are aligned anti-parallel to each other.
- Antiferromagnetism $\rightarrow \downarrow\uparrow\downarrow\uparrow\downarrow\uparrow$
- Ferromagnetism $\rightarrow \uparrow\uparrow\uparrow\uparrow\uparrow\uparrow$
- Ferrimagnetism $\rightarrow \uparrow\downarrow\uparrow\downarrow\uparrow$
- Antiferromagnetic materials lose their own property above a critical temperature called Neel temperature and start behaving like paramagnetic materials. Neel temperature is less than room temperature.
- The variation of magnetic susceptibility of antiferromagnetic material is given by

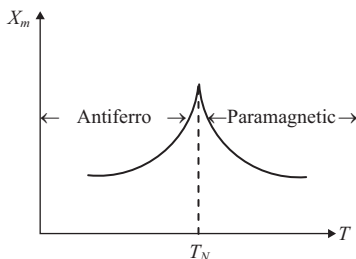


Fig. 1.19

- Curie Weiss law for antiferromagnetic materials is

$$X_m = \frac{C}{T + \theta}$$

where, θ is called paramagnetic curie temperature.

- Molecular field of antiferromagnetic materials opposes the external applied field.
- The external field, try to align the dipole moments in one direction whereas molecular field try to disalign the dipoles.

- Below the Neel temperature, the tendency of dipole moment toward anti-parallel alignments of the moments is stronger enough to act and align the pole anti-parallel in absence of external field.

1.15 MISCELLANEOUS CONDUCTING MATERIALS

1. Highly conducting materials
2. Materials used for solders and contacts
3. Materials of high resistivity
4. Materials used for fuses.

Highly Conducting Materials Properties

- (a) High σ
- (b) Low temperature coefficient
- (c) Sufficient mechanical strength and
- (d) Easily solderable.

Example: Copper

cuprite- Cu_2O
copper glance Cu_2S
copper pyrite-electrolysis

Application of Copper

- (a) Annealed copper is used for conducting bars in machines i.e., Squirrel cage reactor and phase induction motor.
- (b) Hard drawn copper is used in commutator segments of electrical machines.
- (c) The copper with 0.7% Cd is used for contacts and telephone wire.
- (d) Cu with 10% Cr is used for welding electrodes and high current carrying spring up to 400°C .

Aluminum

Aluminum is obtained from Bauxite ($\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$) the resistivity of Al is 1.65 times of copper. The Al is used for making the Bus-bars and transmission line conductors.

Disadvantage of Al: It is not solderable.

Materials Used for Soldering Contacts

Soft solders: 50% Sn + 50% Pb these are used to join copper copper bronze, Ze brass, Pb, etc., at 400°C .

Hard solders: (Cu + Zn alloy) used for joining Brass, Cu, Fe and, steel, at $> 400^\circ\text{C}$.

Materials Used in Electrical Contacts

Materials used for contacts of circuit breakers, are copper, Mo, Ni, Pd, Pt, Ag, Tungsten Cu is used in control relay, tap changers starter switch.

- Ag and its alloys are used in industrial relays. Cu with tungsten are used in transformer tap changers.
- Pt is used, light load contacts such as thermostatic relays Galvanometer contacts, recording instruments, relays in chemical industries.
- Pd is used in light load applications such as telephone relays, thermostatic controls, relays in chemical industry.
- Tungsten is used in vibrator, battery ignition system, electric razors.

Materials used in Fuse

Cu, Al, Pb, Cd, Bi, Sn, Ir and Ag.

Note: Ag is used as fusing element in (High rupture capacity) HRC, fuses.

Brass

- (a) It is the alloy of Cu with Zn and Sn.
- (b) The brass has wear resistance.
- (c) Good weldability and solderability.

QUESTION BANK

LEVEL 1

1. For an insulating material, the dielectric strength and dielectric loss should be respectively
 - (a) High and high
 - (b) low and high
 - (c) High and low
 - (d) low and low
2. The reverse bias breakdown of high speed silicon transistors is due to
 - (a) Avalanche breakdown mechanism at both the junctions
 - (b) Zener breakdown mechanism at both junctions
 - (c) Zener breakdown mechanism at base-collector junction and avalanche breakdown mechanism at base-emitter junction
 - (d) Avalanche breakdown mechanism at base-collector junction and zener breakdown mechanism at base-emitter junction
3. Laser emission from Ruby crystal is because of transition
 - (a) From conduction band to valence band of Al_2O_3
 - (b) From conduction band to one of the levels due to Cr ions
 - (c) Between energy levels introduced by Cr ions
 - (d) Between one of the levels due to Cr ion and valence band of Al_2O_3
4. Wire-wound resistance are used only when
 - (a) Precision is essential
 - (b) Low values are required
 - (c) High power rating is necessary
 - (d) Costly equipments are manufactured
5. When copper is added to silver in small quantity so as to form an alloy, the resistivity of such on alloy is
 - (a) Equal to the resistivity of copper
 - (b) Equal to the resistivity of silver
 - (c) Greater than the resistivity of copper
 - (d) In between the resistivity of silver and copper
6. When a semiconductor bar is heated at one end, a voltage across the bar is developed. If the heated end is positive, the semiconductor is
 - (a) p -type
 - (b) n -type
 - (c) Intrinsic
 - (d) Highly degenerat
7. The conductivity of a semiconductor crystal due to any current carrier is not proportional to
 - (a) Mobility of the carrier
 - (b) Effective density of states in the conduction band
 - (c) Electronic charge
 - (d) Surface states in the semiconductor
8. Amplification of ultrasonic waves is possible in piezoelectric semiconductor under applied electric field. The basic phenomenon involved is known as
 - (a) Electrostriction
 - (b) Acoustic-optic interaction
 - (c) Acoustic-electric interaction
 - (d) Stimulated Brillouin scattering
9. Piezoelectric quartz crystal resonators find application where
 - (a) Signal amplification is required
 - (b) Rectification of the signal is required
 - (c) Signal frequency control is required
 - (d) Modulation of signal is required
10. Which material among the following possesses excellent dielectric properties and good reliability for use in making capacitors?
 - (a) Silicon monoxide
 - (b) Silicon dioxide
 - (c) Tin oxide
 - (d) Chromium oxide
11. Which one of the following is an essential components of electromechanical relays?
 - (a) Graphite rod
 - (b) LED
 - (c) An electromagnet
 - (d) MOSFET
12. In a degenerate semiconductor, the majority carriers are controlled by
 - (a) Fermi-Dirac statistics
 - (b) Maxwell-Boltzman statistics
 - (c) Bose-Einstein (B-E) statistics
 - (d) Pauli's exclusion principle
13. The unit of mobility is
 - (a) $\text{m}^2 \text{V}^{-1} \text{s}^{-1}$
 - (b) $\text{mV}^{-1} \text{s}^{-1}$
 - (c) Vsm^{-1}
 - (d) Vms^{-1}
14. The Haynes-Shockley experiment enables one to determine the
 - (a) Diffusion coefficient of the majority carriers
 - (b) Effective mass of the minority carriers
 - (c) Mobility of the minority carriers
 - (d) Lifetime of the majority carriers
15. In an extrinsic semiconductor, the Hall coefficient R_H
 - (a) Increases with increase of temperature
 - (b) Decreases with increase of temperature
 - (c) Is independent of the change of temperature
 - (d) Changes with the change of magnetic field
16. Even though carbon is in the IV group of the periodic table, it is not used as a semiconductor because is has
 - (a) High dielectric constant
 - (b) Large energy gap $> 5 \text{ eV}$
 - (c) Low temperature coefficient
 - (d) Low thermal conductivity
17. The correct sequence of the following materials in the increasing order of conductivity is
 - (a) Silicon doped with boron-Silver-Aluminium Intrinsic silicon
 - (b) Intrinsic silicon-Aluminium-Silver-Silicon doped with boron
 - (c) Aluminum-Intrinsic silicon-Silicon doped with boron-Silver
 - (d) Intrinsic silicon-Silicon doped with boron-Aluminium-Silver

1.20 ■ Materials and Components

18. Which of the following materials are piezoelectric?
 - (a) Mica and quartz
 - (b) Mica, barium titanate and quartz
 - (c) Mica and diamond
 - (d) Barium titanate and quartz
19. The correct sequence of the following materials in the increasing order of magnetic susceptibility is
 - (a) Diamagnetic-Ferromagnetic-Paramagnetic-Superconductor
 - (b) Ferromagnetic-Paramagnetic-Diamagnetic-Superconductor
 - (c) Paramagnetic-Diamagnetic-Superconductor-Ferromagnetic
 - (d) Superconductor-Diamagnetic-Paramagnetic-Ferromagnetic
20. An LED made using GaAs emits radiation in
 - (a) Visible region
 - (b) Ultraviolet region
 - (c) Infra red region
 - (d) Microwave frequency region
21. Which one of the following statements is correct? Ionic crystals are
 - (a) Hard and brittle
 - (b) Soft and elastic
 - (c) Hard and corrosive
 - (d) Soft and inflammable
22. Ceramic insulators undergo a glazing process to reduce the possibility of electric breakdown. What is the effect of this process?
 - (a) It makes the surface non-absorbent
 - (b) It makes the surface reflecting
 - (c) It makes the surface curvature-free
 - (d) It makes the surface moist
23. The material which has the property of becoming electrically polarized in response to an applied mechanical stress is termed as
 - (a) Ferroelectric
 - (b) Piezoelectric
 - (c) Optoelectronic
 - (d) Superconducting
24. The magnetic material in which permanent atomic magnetic dipoles have parallel orientation is termed as which one of the following?
 - (a) Diamagnetic
 - (b) Paramagnetic
 - (c) Ferromagnetic
 - (d) Ferrimagnetic
25. Which one of the following materials is a ceramic material?
 - (a) Mica
 - (b) Zinc sulphide
 - (c) Antimony
 - (d) Copper
26. The material for the core in a power transformer must have
 - (a) High resistivity and low permeability
 - (b) Low value of saturation magnetization and high resistivity
 - (c) High permeability and low resistivity
 - (d) High permeability and high saturation magnetization
27. Magnetic cores required for RF applications have
 - (a) High hysteresis and eddy current losses
 - (b) High hysteresis and low eddy current losses
 - (c) Low hysteresis and high eddy current losses
 - (d) Low hysteresis and eddy current losses
28. At what condition of surrounding air, does electro-chemical breakdown occur?
 - (a) High temperature and high humidity
 - (b) High temperature and low humidity
 - (c) Low temperature and high humidity
 - (d) Low temperature and low humidity
29. Which one of the following exhibits the most well-defined X-ray diffraction pattern?
 - (a) A polycrystalline aggregate
 - (b) An amorphous material
 - (c) A single crystalline material
 - (d) A plasticity deformed crystal
30. What is the correct arrangement of the following alloys in decreasing order of resistivity?
 - (a) German silver–constantan –monel metal
 - (b) German silver–monel metal–constantan
 - (c) Constantan–monel metal–German silver
 - (d) Constantan–German silver–monel metal
31. The piezoelectric effect is the polarization of a dielectric under the influence of
 - (a) Light
 - (b) Mechanical stress
 - (c) Electrical stress
 - (d) Heat
32. Piezoelectricity is the reverse effect of
 - (a) Electroluminescence
 - (b) Electrostriction
 - (c) Peltier effect
 - (d) Hall effect
33. When a solid crystal of sodium is formed, the 3s-band will have
 - (a) Half as many states as the number of atoms
 - (b) Same number of states as there are atoms
 - (c) Twice as many states as there are atoms
 - (d) No states at all
34. The relaxation time (τ) in a perfect dielectric is
 - (a) 0
 - (b) 1
 - (c) $1 < \tau < \infty$
 - (d) ∞
35. What type of magnetic behaviour is observed in a type I superconductor?
 - (a) Perfect diamagnetism
 - (b) Perfect paramagnetism
 - (c) Perfect ferromagnetism
 - (d) Perfect ferrimagnetism
36. The Hall coefficient of an intrinsic secondary is
 - (a) Positive under all conditions
 - (b) Negative under all conditions
 - (c) Zero under all conditions
 - (d) Zero at 0 K
37. If the lattice temperature is increased, then the Hall coefficient of a semiconductor will
 - (a) Decrease
 - (b) Increase
 - (c) First increase to a peak and then decrease
 - (d) Remain constant
38. The decreasing order of the electrical sensitivities coefficient, is
 - (a) Nichrome, Silicon, Diamond
 - (b) Silicon, Diamond, Nichrome

- (c) Diamond, Nichrome, Silicon
(d) Diamond, Silicon, Nichrome
39. The actual field seen by an atom in dielectric is
(a) Lower than the applied field
(b) Higher than the applied field
(c) Equal to the applied field
(d) Higher or lower depending upon the particular solid
40. Ultrasonic amplification through electron–phonon interaction is generally achieved using a
(a) Paramagnetic material
(b) Piezoelectric material
(c) Superconductor
(d) Elemental semiconductor
41. As the temperature of a ‘p’ type semiconductor is gradually and continuously increased, the Fermi level will move
(a) Into the valence band
(b) Into the conduction band
(c) Towards the middle of the forbidden gap
(d) Into the region between the acceptor level and the valence band
42. The residual resistivity of metals
(a) Is essentially independent of temperature
(b) Increases linearly with increasing temperature
(c) Decreases linearly with increasing temperature
(d) Initially increases linearly with temperature and then remains constant
43. A type I superconductor maintained at a temperature $T < T_c$ is subjected to magnetic field $H < H_c$. The superconductor will exhibit
(a) perfect diamagnetism (b) partial diamagnetism
(c) perfect paramagnetism (d) partial paramagnetism
44. The magnetic susceptibility of a paramagnetic material is
(a) less than zero (b) less than one but positive
(c) greater than one (d) equal to zero
45. Magnetostriction is a phenomenon whereby the magnetization of a ferromagnetic material leads to a change in
(a) relative permeability
(b) physical dimensions
(c) spontaneous magnetization
(d) magnetic susceptibility
46. Silicon carbide reinforced aluminium metal matrix composites find application in
(a) The manufacture of transformer cores
(b) The manufacture of cutting tools
(c) The manufacture of standard resistors
(d) Aerospace industry
47. GaAs LEDs emit radiation in the
(a) Ultra-violet region
(b) Violet–blue–green range of the visible region
(c) Visible region
(d) Infra-red region
48. Which one of the following classes of materials can be categorized as ferrites?
(a) Plastics (b) Metals
(c) Alloys (d) Ceramics
49. The correct sequence of increasing order of electrical resistivity of the given materials is
(a) Diamond doped germanium silicon, gold
(b) Gold, silicon, doped germanium, diamond
(c) Gold, doped germanium, silicon, diamond
(d) Gold, diamond, silicon doped germanium
50. Fermi level is the
(a) Highest occupied energy level at zero Kelvin
(b) Highest occupied energy level at 0°C
(c) Energy level at which electron emission occurs
(d) Minimum energy level in the conduction band
51. A ferromagnetic material exhibits different characteristics above and below the
(a) Joule’s temperature (b) Faraday temperature
(c) Curie temperature (d) Neel temperature
52. The spins in a ferromagnetic material are
(a) All aligned parallel
(b) Partially aligned and parallel without exactly cancelling out sub-lattice magnetism
(c) Randomly oriented
(d) All aligned and parallel such that the sub-lattice magnetism cancels out exactly
53. The temperature coefficient of resistance of an insulator is
(a) Positive and independent of temperature
(b) Negative and independent of temperature
(c) Negative and dependent on temperature
(d) Positive and dependent on temperature
54. Piezoelectric materials owe their property to the
(a) Presence of a centre of symmetry
(b) Lack of a centre of symmetry
(c) Presence of axis of symmetry
(d) Lack of axis of symmetry
55. The phenomenon by which a ferromagnetic material is magnetized to its final state by a magnetic field is attributed to
(a) Eddy currents and magnetic viscosity
(b) Magnetic viscosity and hysteresis
(c) Hysteresis and eddy current
(d) Aging and magnetic viscosity
56. The ceramic dielectrics used in electrical engineering include
(a) Cermet and silicide
(b) Porcelain and cermet
(c) Cordierite and porcelain
(d) Silicide and cordierite
57. Liquid crystal material is used in
(a) Ultrasonic amplification and display devices
(b) Thermal sensors and transducers
(c) Display devices and thermal sensors
(d) Transducers and ultrasonic amplification

1.22 ■ Materials and Components

58. Semiconductor A has higher band gap than semiconductor B . If both A and B have same dimensions, the same number of electrons at a given temperature and the same electron and hole mobilities, then
- A has the same number of holes as B
 - A has a larger number of holes than B
 - A has less number of holes than B
 - Any of the above statements at (a), (b) or (c) could be true
59. Which of the following crystallographic defects contributes to electron defects?
- Thermal Vibration
 - Point defects
 - Line defects
 - Surface defects
- Select the correct answer using the codes given below
- Codes:**
- 1, 2 and 3
 - 2, 3 and 4
 - 1, 3 and 4
 - 1, 2 and 4
60. Above the Curie temperature, the hysteresis loop of a ferroelectric material can be described by a
- Parabola
 - Cycloid
 - Straight line
 - Point
61. Orientational polarization is
- Inversely proportional to temperature and proportional to the square of the permanent dipole moment
 - Proportional to temperature as well as to the square of the permanent dipole moment
 - Proportional to temperature and inversely proportional to the square of the permanent dipole moment
 - Inversely proportional to temperature as well as to the square to the square of dipole moment
62. In a piezoelectric crystal oscillator, the oscillation or tuning frequency is linearly proportional to the
- Mass of the crystal
 - Square root of the mass of the crystal
 - Square of the mass of the crystal
 - Inverse of the square root of the mass of the crystal
63. Some of electrons are injected into the interior of a conductor surrounded by an insulator. The injected electrons will
- Distribute themselves uniformly
 - Distribute themselves randomly
 - Be confined at the point of injection
 - Travel to the surface of the conductor
64. The coercive force in ferromagnetic material is related to the
- Area enclosed by the B-H loop
 - Intercept on the negative H-axis of the B-H loop
 - Intercept on the positive B-axis of the B-H loop
 - Maximum value of B on the B-H loop
65. The Hall effect voltage in intrinsic silicon
- Is positive
 - Is zero
 - Is negative
 - Changes sign on application of magnetic field
66. Electrical conductivity of copper reduces with addition of a small amount of nickel because
- The mobility decreases due to creation of new scattering centres for electrons
 - Nickel is ferromagnetic
 - Less free electrons are available for conduction
 - The electrons of copper become bound to nickel atoms and are not free to move
67. When a transition occurs to the superconducting state, the magnetic flux is excluded from the material. This is known as
- Magnetophobic effect
 - Silsbee effect
 - Meissner effect
 - Copper effect
68. Cu_2MnAl is
- piezoelectric
 - paramagnetic
 - ferromagnetic
 - ferrimagnetic
69. In a semiconductor J , J_p and J_n indicate total diffusion current density, hole current density and electron current density respectively, $\frac{\partial n}{\partial x}$ and $\frac{\partial p}{\partial x}$ are the electrons and hole concentration gradients respectively in x direction and D_p and D_n are the hole and electron diffusion constants respectively. Which one of the following equation is correct? (q denotes the charge of an electron)
- $J_n = -q D_n \frac{\partial n}{\partial x}$ for electrons
 - $J_p = -q D_p \frac{\partial p}{\partial x}$ for holes
 - $J = -q D_p \frac{\partial p}{\partial x} - q D_n \frac{\partial n}{\partial x}$
 - $J = q D_p \frac{\partial p}{\partial x} + D_n \frac{\partial n}{\partial x}$
70. In an intrinsic semiconductor, the mobility of electrons in the conduction band is
- Zero
 - Less than the mobility of holes in the valence band
 - Equal to the mobility of holes in the valence band
 - Greater than the mobility of holes in the valence band
71. A piece of copper and an other of germanium are cooled from room temperature to 80°K . The resistance of
- Each of them increases
 - Each of them decreases
 - Copper increases and germanium decreases
 - Copper decreases and germanium increases
72. The nature of crystal ending in germanium is
- ionic
 - metallic
 - covalent
 - Vander Waal type
73. Which of the following will serve as a donor impurity in silicon?
- Boron
 - Indium
 - Germanium
 - Antimony
74. The mean free path for electron drift increases with
- purity
 - strain hardening
 - elastic modulus
 - none of the above

75. Two group IV elements have the same diamond cubic structure. The one with the larger is expected to have the smaller energy gap
 (a) Packing factor
 (b) Coordination number
 (c) Number of valence electrons
 (d) Atomic weight
76. Polarization is a measure of
 (a) Dielectric constant per unit volume
 (b) Voltage gradient of produce electrical breakdown
 (c) Product of charge and distance
 (d) Excess charge density
77. The temperature below which certain materials are antiferromagnetic and above which they are paramagnetic is called
 (a) Weiss temperature
 (b) Curie temperature
 (d) Double point temperature
 (c) Neel temperature
78. Pure metals generally have
 (a) high conductivity and low temperature coefficient
 (b) high conductivity and large temperature coefficient
 (c) low conductivity and zero temperature coefficient
 (d) low conductivity and high temperature coefficient
79. Magnetostriction
 (a) induced magnetism
 (b) volume changes accompanying magnetization
 (c) rate of magnetization
 (d) rate of loss of magnetism
80. The hot resistance of the filament of a bulb is higher than the cold resistance because the temperature coefficient of the filament is
 (a) negative (b) infinite
 (c) zero (d) positive
81. For a second order system, if both the roots of the characteristic equation are real, then the value of damping ratio will be
 (a) less than unity (b) equal to unity
 (c) equal to zero (d) greater than unity
82. A pole of driving point admittance function implies
 (a) Zero current for a finite value of driving voltage
 (b) Zero voltage for a finite value of driving current
 (c) An open circuit condition
 (d) None of (a), (b) and (c) mentioned in the question
83. Cauer and Foster forms of realizations are used only for
 (a) Driving point reactance functions
 (b) Transfer reactance functions
 (c) Driving point impedance functions
 (d) Transfer impedance functions
84. Superposition theorem is not applicable for
 (a) Voltage calculations
 (b) Bilateral elements
 (c) Power calculations
 (d) Passive elements
85. At resonant frequency a R-L-C series circuit draws maximum current due to the reason that
 (a) the difference between capacitance reactance and inductance reactance is zero
 (b) the impedance is more than to resistance
 (c) the voltage across the capacitor equal the applied voltage
 (d) the power factor is less than unity
86. When two-Wattmetre method of measurement of power is used to measure power in a balanced three phase circuit; if the Wattmetre reading is zero, then
 (a) power consumed in the circuit is zero
 (b) power factor of the circuit is zero
 (c) power factor is unity
 (d) power factor is 0.5
87. Which one of the following material does not have a covalent bond?
 (a) Metal (b) Silicon
 (c) Organic polymers (d) Diamond
88. Piezoelectric effect is generally observed in
 (a) Insulators
 (b) Insulators and semiconductors
 (c) Conductors and superconductors
 (d) Conductors and semiconductors
89. High frequency transformer cores are generally made of
 (a) cast iron (b) mu-metal
 (c) ferrite (d) graphite
90. Consider the following statements
 In the case of paramagnetic materials, there
 1. is no permanent dipole moment
 2. are permanent dipole moments
 3. is no alignment dipoles in the absence of magnetic field
 4. is no interaction among the dipoles
 Which of these statement(s) is/are correct?
 (a) 1 alone (b) 3 and 4
 (c) 2 and 4 (d) 2, 3 and 4
91. Total number of electrons that can be accommodated in various electron states in a valence band of a given solid is equal to
 (a) Atomic number of the solid
 (b) Half the number of atoms in the solid
 (c) The number of atoms in the solid
 (d) Twice the number of atoms in the solid
92. The conductivity of a conducting material on being subject to critical magnetic field changes to
 (a) normal state
 (b) unstable state
 (c) temperature-independent state
 (d) temperature-dependent state
93. A large value of the exchange interaction energy in a ferromagnetic material implies
 (a) Large saturation magnetization
 (b) High Curie temperature
 (c) High melting point
 (d) Large diamagnetic susceptibility

1.24 ■ Materials and Components

94. Which one of the following pairs is not correctly matched?
- (a) Copper Diamagnetic
 - (b) Sodium Anti ferromagnetic
 - (c) Iron Ferromagnetic
 - (d) Ferrite Ferrimagnetic
95. For a semiconductor, which one of the following statements is not correct?
- (a) When an electron and a hole recombine, energy must be liberated.
 - (b) Electrons in the conduction band can acquire a net acceleration from a field because there are empty energy levels available.
 - (c) An electron in the valence band cannot be accelerated by the field unless there are empty energy levels available.
 - (d) Holes cannot be accelerated by the field unless there are empty energy levels available.
96. Which of the following has the greatest mobility?
- (a) Positive ion
 - (b) Negative ion
 - (c) Electron
 - (d) Hole
97. At optical frequencies, the major contribution to the total polarization comes from
- (a) space charge polarization
 - (b) orientation polarization
 - (c) ionic polarization
 - (d) electronic polarization
98. Which of the following insulating materials has the least affinity for moisture?
- (a) Cotton
 - (b) Paper
 - (c) Asbestos
 - (d) Mica
99. Which of the following statements is not true
- (a) Superconductors show perfect diamagnetism
 - (b) Superconductors have almost zero resistivity
 - (c) The external magnetic field has no effect on superconductors
 - (d) Entropy increases on going from superconducting state to normal state
100. De Broglie wavelength associated with a material particle is
- (a) Inversely proportional to its energy
 - (b) Directly proportional to momentum
 - (c) Directly proportional to its energy
 - (d) Inversely proportional to momentum
101. Which of the following is piezoelectric material?
- (a) Quartz
 - (b) Silica sand
 - (c) Corundum
 - (d) Polystyrene
102. With an increase temperature, the Fermi level in an intrinsic semiconductor
- (a) Moves closer to the conduction and edge
 - (b) Moves closer to the valence band edge
 - (c) Moves into the conduction band
 - (d) Remains at the centre of the forbidden gap
103. Which one of the following is not true for Sulphur Hexafluoride gas?
- (a) It is electronegative in nature
 - (b) It has high dielectric strength
 - (c) It is non-toxic
 - (d) It is highly inflammable
104. Which one of the following materials has the highest dielectric strength?
- (a) Polystyrene
 - (b) Marble
 - (c) Cotton
 - (d) Transformer oil
105. The losses in a dielectric subject to an alternating electric field are determined by
- (a) Real part of the complex dielectric constant
 - (b) Imaginary part of the complex dielectric constant
 - (c) Absolute value of the complex dielectric constant
 - (d) Ratio of the magnitudes of the real and imaginary parts of the complex dielectric constant
106. In a solid or liquid dielectric with externally applied electric field; as the interatomic distance increases the internal field E_i
- (a) Increases
 - (b) Decreases
 - (c) Remains unaltered
 - (d) Increases or decreases based on temperature
107. According to Wiedemann-Franz law, the ratio of thermal conductivity to electrical conductivity of a conductor is
- (a) Independent of temperature
 - (b) Directly proportional temperature
 - (c) Inversely proportional to temperature
 - (d) Inversely proportional to square of temperature
108. Which one of the following statements is correct for four-point probe method of determining resistivity?
- (a) The sample must be extrinsic
 - (b) The current source is connected to the two inner probes
 - (c) One probe point must inject minority carriers
 - (d) Current flows only in a small area of the sample
109. The development of barrier potential in the depletion zone of a PN junction consequent to
- (a) Diffusion of majority carriers across junction
 - (b) Drift of minority carriers across junction
 - (c) Generation of minority carriers due to thermal energy
 - (d) Initial flow of conduction current
110. An intrinsic semiconductor at a temperature of absolute zero behaves like insulator because of
- (a) Non-availability of free electrons
 - (b) Non-recombination of electrons with holes
 - (c) Low drift velocity of free electrons
 - (d) Low (almost zero) electron energy

LEVEL 2

- The number of stress coefficients or constraints which characterize a piezoelectric material is
 - 24
 - 18
 - 9
 - 3
- The room temperature resistivity (in ohm-metre) of pure silicon is
 - 3000
 - 300
 - 30
 - 3
- The insulator filling the space between the plates of a parallel plate capacitor is of area 10^4 mm^2 and thickness 1 mm. Its resistivity is $10^{10} \text{ ohm metre}$. When a dc voltage of 1 kV is applied, the dielectric loss will be
 - 10^{-3} W
 - 10^{-2} W
 - 10^2 W
 - 10^3 W
- When a dielectric is subjected to an alternating field, the real part of the complex relative dielectric constant is found to be 2.5. The loss tangent is 0.004. The imaginary part of the relative dielectric constant is
 - 0.01
 - 2.496
 - 25.04
 - 625.63
- At 300 K, the density of electrons in a certain metal is $6 \times 10^{28}/\text{m}^3$ and its relaxation time is 10^{-14} s . The thermal conductivity of the metal is
 - 70.63 W/m/K
 - 123.93 W/m/K
 - 508 W/m/K
 - 1359.68 W/m/K
- The resistivity and electron density in a metal are $1.54 \times 10^{-8} \text{ ohm-m}$ and $5.8 \times 10^{28}/\text{m}^3$ respectively. Electron mobility in the metal (in units of $\text{m}^2 \text{ V}^{-1} \text{ s}^{-1}$) is
 - 0.007
 - 0.07
 - 0.7
 - 1.05
- The Curie point of Rochelle salt is
 - 1000°C
 - 250°C
 - 100°C
 - 10°C
- The energy band gap of germanium is 0.72 eV at 300 K. The fraction of the total number of electrons (conduction band as well as valence band) in the conduction band at 300 K is
 - 10^{-6}
 - 10^{-4}
 - 10^{-2}
 - 0.1
- The Hall coefficient of a specimen of doped semiconductor is $3.06 \times 10^{-4} \text{ m}^3 \text{ C}^{-1}$ and the resistivity of the specimen is $8.93 \times 10^{-3} \text{ ohm metre}$. The majority carrier mobility (in units of $\text{m}^2 \text{ V}^{-1} \text{ s}^{-1}$) will be
 - 0.0078
 - 0.035
 - 0.151
 - 0.350
- When the time period of the applied voltage is much shorter than the relaxation time of a polarization process, the loss of angles d is
 - zero
 - between 0 and 90°
 - 90°
 - greater than 90°
- The total iron loss in a transformer core at normal flux density was measured at 25 Hz and 50 Hz and was found to be 250 W and 800 W respectively. The hysteresis loss at 50Hz would be
 - 100 W
 - 150 W
 - 200 W
 - 600 W
- Silicon contains 5×10^{28} atoms per cubic metre. If it is doped with two parts per million of arsenic, then the electron density at room temperature will be approximately
 - $4 \times 10^{23} \text{ m}^{-3}$
 - 10^{23} m^{-3}
 - $2 \times 10^6 \text{ m}^{-3}$
 - 10^4 m^{-3}
- The resistance of a circuit is found by measuring current flowing and the power fed into the circuit. If the limiting error in the measurement of power and current are $\neq 1.5\%$ and $\neq 1.0\%$ respectively, the limiting error in the measurement of resistance will be
 - $\neq 1\%$
 - $\neq 1.5\%$
 - $\neq 2.5\%$
 - $\neq 3.5\%$
- If a coil has diameter d' number of turns N' and form factor F' then the inductance of the coil is proportional to
 - $N^2 dF$
 - $N d^2 F$
 - $N^2 \left(\frac{d^2}{F} \right)$
 - $N^2 \left(\frac{d}{F} \right)$
- A four-point probe method is used to evaluate the sheet resistance of a semiconductor epitaxial layer. If a probe current of 10 mA produces a voltage drop of 0.22 V between the inner probes, then the sheet resistance of the layer is
 - 100 Ω/square
 - 215 Ω/square
 - 572 Ω/square
 - 1000 Ω/square
- A piezoelectric crystal has Young's modulus of 130 GPa. The uniaxial stress that must be applied to increase its polarization from 550 to 555 Cm^{-2} is, nearly
 - 2.798 GPa
 - 2.175 GPa
 - 1.593 GPa
 - 1.182 GPa
- The outermost electronic configuration of a cobalt is $3d^2 4s^2$. Its magnetic moment is
 - 9 Bohr magnetrons
 - 7 Bohr magnetrons
 - 5 Bohr magnetrons
 - 3 Bohr magnetrons
- When certain percentage of silicon is added to iron, the resistivity of the iron increases by a factor of 5. If a transformer core is made out of this iron, as compared to the previous value when silicon was not added, the eddy current loss will be
 - 77%
 - 80%
 - 83%
 - 86%
- The correct sequence of the following in the increasing order of the values of permittivity is
 - Air, Vacuum, $T_a O_2$ Glass
 - Air, Vacuum, Glass, $T_a O_2$
 - Vacuum, Air, $T_a O_2$ Glass
 - Vacuum, Air Glass, $T_a O_2$

20. The Hall constant in P-Si bar is given by $5 \times 10^3 \text{ cm}^3/\text{Coulomb}$. The hole concentration in the bar is given by
 (a) $1.00 \times 10^{15}/\text{cm}^2$ (b) $1.25 \times 10^{15}/\text{cm}^3$
 (c) $1.50 \times 10^{15}/\text{cm}^2$ (d) $1.6 \times 10^{15}/\text{cm}^3$
21. The electrical resistivity of sodium silicate glass is $10^5 \Omega\text{m}$ where as that of pure silica glass is $10^{17} \Omega\text{m}$. This vast difference of 12 orders of magnitude is due to which one of the following reasons?
 (a) The loosely-bound sodium ions in the silicate
 (b) The impurities in silica
 (c) The difference in the crystal structures
 (d) The presence of free electrons in the silicate
22. What is the approximate mobility of holes in Germanium at room temperature?
 (a) $4500 \text{ cm}^2/\text{V.s}$ (b) $2400 \text{ cm}^2/\text{V.s}$
 (c) $1800 \text{ cm}^2/\text{V.s}$ (d) $900 \text{ cm}^2/\text{V.s}$
23. A thin resistive film having length (l), width (w) and thickness (t) is used as a resistor (R_1) for conducting current in the direction of l . If the film is connected to serve as a resistor (R_2) for conducting current in the direction of w , then what is the value of R_1/R_2 ?
 (a) l/w (b) w/l
 (c) l^2/w^2 (d) w^2/l^2
24. Which of these ceramic materials have relative permittivity ϵ_r between 3 to 6 and loss angle $\tan \delta$ between 50×10^{-4} to 100×10^{-4} ?
 (a) Strontium zirconate SrZrO_3
 (b) Titanium oxide TiO_2
 (c) Calcium titanate CaTiO_3
 (d) Barium titanate BaTiO_3
25. Frequency spectrum of a signal lies within the band $f_0 \leq f \leq f_1 \text{ Hz}$ to sample the signal properly, the sampling period should be
 (a) $> \frac{1}{2f_0}$ (b) $< \frac{2}{f_0}$
 (c) $< \frac{1}{2f_1}$ (d) $> \frac{2}{f_1}$
26. For insulators, the forbidden gap is of the order of
 (a) 5 eV (b) 1 eV
 (c) 0.1 eV (d) zero
27. The band-gap of a semiconductor is 1.43 eV. Its cut-off wavelength is
 (a) $1 \mu\text{m}$ (b) $0.81 \mu\text{m}$
 (c) $0.56 \mu\text{m}$ (d) $0.27 \mu\text{m}$
28. By inserting a slab of dielectric material between the plates of a parallel plate capacitor, the energy stored in the capacitor has increased three times. The dielectric constant of the material is
 (a) 9 (b) 3
 (c) $\frac{1}{3}$ (d) $\frac{1}{9}$
29. In a conductor of size $20 \text{ mm} \times 10 \text{ mm} \times 10 \text{ mm}$, the wavelength of the slowest moving free electron is
 (a) 5 mm (b) 10 mm
 (c) 20 mm (d) 40 mm
30. Assuming the Fermi level E_F to be independent of temperature, E_F may be defined as the level with an occupancy probability of
 (a) 0% (b) 50%
 (c) 75% (d) 100%
31. The complex dielectric constant of a material is given by the expression
 $\epsilon = \epsilon' - j\epsilon''$
 If a parallel plate capacitor with area ' A ' and separation ' d ' is formed with this material as a dielectric, the loss factor will be
 (a) $\frac{(A\epsilon')}{(d\epsilon'')}$ (b) $\frac{\epsilon''}{\epsilon'}$
 (c) $\tan^{-1}\left(\frac{(A\epsilon')}{(d\epsilon'')}\right)$ (d) $\tan^{-1}\left(\frac{(d\epsilon'')}{(A\epsilon')}\right)$
32. The transition temperature of Mercury at which it becomes superconductive is
 (a) 4.12°F (b) 4.12°C
 (c) 4.12 K (d) 41.2 K
33. About 4% silica is added in iron to be used as a soft magnetic material. The major reason for this is to
 (a) Increase permeability of the material
 (b) Increase electrical resistivity of the material
 (c) Increase the coercive force
 (d) Increase the saturation flux density
34. The average drift velocity V_d of electrons in a metal is related to electric field E and collision time T as
 (a) $V_d = \frac{Q_e E T}{m_e}$ (b) $V_d = m_e Q_e T$
 (c) $V_d = \frac{m_e Q_e T}{2E}$ (d) $V_d = \frac{Q_e E T}{2m_e}$
35. Consider the following statements:
 E_f^n and E_f^p are the energies of the Fermi level on the n and p sides of p - n junction diode, respectively. They will vary with applied bias as follows:
 1. $E_f^n = E_f^p$ with no bias applied
 2. E_f^n increases and E_f^p decreases with reverse bias
 3. E_f^n decreases and E_f^p increases with forward bias
 4. E_f^n decreases and E_f^p decreases with reverse bias
 5. E_f^n increases and E_f^p decreases with reverse bias
 Select the correct answer using the codes given below:
 (a) 1, 4 and 5 (b) 2 and 3
 (c) 4 and 5 (d) 1, 2 and 3
36. Given that
 q = charge of an electron
 R = radius of the electron orbit
 ω = angular velocity of electron rotation,
 The magnetic dipole moment of the electron in orbit is given by
 (a) $0.5 q \omega R$ (b) $P = \epsilon_0 E$
 (c) $0.5 q \omega R^2$ (d) $0.5 q \omega^2 R$

37. A single layer air-cored coil having turns has an inductance ' L '. If a new coil is formed by having $2n$ turns while retaining the coil length and diameter at the same value as before, the inductance of the new coil will be
 (a) $L/2$ (b) $2L$
 (c) $4L$ (d) $L/4$
38. As per Curie-Weiss law, the magnetic susceptibility of a material varies as
 (a) T^{-2} (b) $1/T$
 (c) T (d) T^2
39. Yttrium-iron garnet ($\text{Y}_2\text{Gd}_{0.98}\text{Fe}_5\text{O}_{12}$) is a soft magnetic material suitable for use in applications involving
 (a) Direct current (b) AC of 50 to 60 Hz
 (c) AC of a few kHz (d) AC of a few hundred MHz
40. The carrier mobility in a semiconductor is $0.4 \text{ m}^2/\text{Vs}$. Its diffusion constant at 300 K will be (m^2/s)
 (a) 0.43 (b) 0.16
 (c) 0.04 (d) 0.01
41. The relative dielectric constant of barium titanate at 100°C is about
 (a) 1 (b) 5
 (c) 50 (d) 2000
42. Electrical conductivity of metals expressed in $\text{ohm}^{-1} \text{ m}^{-1}$ is of the order of
 (a) 10^{10} (b) 10^5
 (c) 10^{-4} (d) 10^{-6}
43. The emission of an alpha particle from the nucleus of $^{226}_{88}\text{Ra}$ will yield
 (a) $^{223}_{86}\text{Rn}$ (b) $^{222}_{86}\text{Rn}$
 (c) $^{222}_{88}\text{Rn}$ (d) $^{222}_{88}\text{Rn}$
44. The electrical conductivity of metals is typically of the order of ($\text{ohm}^{-1} \text{ m}^{-1}$)
 (a) 10^7 (b) 10^5
 (c) 10^{-4} (d) 10^{-6}
45. Which of the following closely represents the temperature (T), Resistance (R) characteristics of a thermistor?
 (a) $R_T = a R_o e^{b/T}$ (b) $R_T = a R_o e^{-b/T}$
 (c) $R_T = -a R_o e^{-b/T}$ (d) $R_T = -a R_o e^{b/T}$
46. $^{235}_{92}\text{U}$ nucleus absorbs a slow neutron and undergoes fission into $^{140}_{50}\text{X}$ and $^{94}_{38}\text{S}$ nuclei. The other particles produced in this fission process are
 (a) 1 β and 1 neutron (b) 2 β and 1 neutron
 (c) 2 neutron (d) 3 neutron
47. The energy required to change the speed of one electron from rest to $0.6c$ is nearly
 (a) 0.085 MeV (b) 0.13 MeV
 (c) 0.26 MeV (d) 0.37 MeV
48. According to the classical free electron theory, the relaxation time and mean free path for aluminum are respectively $0.75 \times 10^{-10} \text{ s}$ and 0.88 nm . Given that the density of aluminum is 2700 kg/m^3 and the atomic weight of aluminum is 26.98, the resistivity of aluminum is
 (a) $1.73 \times 10^{-8} \text{ } \Omega\text{m}$ (b) $1.47 \times 10^{-8} \text{ } \Omega\text{m}$
 (c) $2.62 \times 10^{-8} \text{ } \Omega\text{m}$ (d) $4.32 \times 10^{-8} \text{ } \Omega\text{m}$
49. A sample of pure Cu has resistivity of $1.5 \times 10^{-8} \text{ ohm-metre}$ at 0°C . If nickel whose resistivity is $1.6 \times 10^{-8} \text{ ohm-metre}$ is added to copper, the resistivity of the resulting alloy will
 (a) Increase depending upon the amount of nickel added
 (b) Decrease in all cases
 (c) Remain the same as before
 (d) Decrease but will not be dependent on the amount of nickel added
50. The relaxation time (τ) in a perfect dielectric is
 (a) 0 (b) 1
 (c) $1 < \tau < \infty$ (d) ∞
51. The conductivity of a metal at ultraviolet frequency (10^{14} Hz) approximately equals
 (a) Infinity (b) Zero
 (c) dc conductivity (d) Half of dc conductivity
52. Constantan is an alloy composed of
 (a) 86% copper, 12% manganese and 2% nickel
 (b) 76% nickel, 21 chromium, 2% manganese and 1% iron
 (c) 60% copper and 40% nickel
 (d) 40% copper, 40% nickel and 20% carbon
53. The room temperature resistivity (in ohm-metre) of pure silicon is
 (a) 3000 (b) 300
 (c) 30 (d) 3
54. In a periodic linear chain of atoms, the interatomic chain is $3.14 \text{ \AA}$. The first Brillouin zone exists between the wave number (in units of m^{-1})
 (a) Zero and $+2 \times 10^{13}$
 (b) -3.14×10^{12} and $+3.14 \times 10^{12}$
 (c) -3.14×10^{12} and zero
 (d) -10^{10} and $+10^{10}$
55. The insulator filling the space between the plates of a parallel plate capacitor is of area 10^4 mm^2 and thickness 1 mm . Its resistivity is $10^{10} \text{ ohm metre}$. When a dc voltage of 1 kV is applied, the dielectric loss will be
 (a) 10^{-3} W (b) 10^{-2} W
 (c) 10^2 W (d) 10^3 W
56. When a dielectric is subjected to an alternating field, the real part of the complex relative dielectric constant is found to be 2.5. The loss tangent is 0.004. The imaginary part of the relative dielectric constant is
 (a) 0.01 (b) 2.496
 (c) 25.04 (d) 625.63
57. At 300 K, the density of electrons in a certain metal is $6 \times 10^{28} / \text{m}^3$ and its relaxation time is 10^{-14} s . The thermal conductivity of the metal is
 (a) 70.63 W/m/K (b) 123.93 W/m/K
 (c) 508 W/m/K (d) 1359.68 W/m/K

58. The resistivity and electron density in a metal are 1.54×10^{-8} ohm-m and $5.8 \times 10^{28}/\text{m}^3$ respectively. Electron mobility in the metal (in units of $\text{m}^2 \text{V}^{-1} \text{s}^{-1}$) is
 (a) 0.007 (b) 0.07
 (c) 0.7 (d) 1.05
59. Which of the following are associated with soft superconductors?
 1. Silsbee's rule 2. Meissner effect
 3. Faraday rotation 4. Curie-Weiss law
 Select the correct answer using the codes given below Codes
 (a) 2, 3 and 4 (b) 1 and 3
 (c) 1 and 2 (d) 2 and 4
60. Which one of the following materials can be used to produce temperatures as low as 250°C ?
 (a) KH_2PO_4 (b) BaTiO_2
 (c) CeF_2 (d) InGaAs
61. The Curie point of Rochelle salt is
 (a) 1000°C (b) 250°C
 (c) 100°C (d) 10°C
62. The energy band gap of germanium is 0.72 eV at 300 K. The fraction of the total number of electrons (conduction band as well as valence band) in the conduction band at 300 K is
 (a) 10^{-6} (b) 10^{-4}
 (c) 10^{-2} (d) 0.1
63. The Hall coefficient of a specimen of doped semiconductor is $3.06 \times 10^{-4} \text{ m}^3 \text{C}^{-1}$ and the resistivity of the specimen is 8.93×10^{-3} ohm metre. The majority carrier mobility (in units of $\text{m}^2 \text{V}^{-1} \text{s}^{-1}$) will be
 (a) 0.0078 (b) 0.035
 (c) 0.151 (d) 0.350
64. Which one of the following materials is piezoelectric?
 (a) Pb_2Au (b) BaTiO_3
 (c) MgAl_2O_4 (d) NiFe_2O_4
65. Two initially identical samples A and B of pure germanium are doped with donors to concentrations of $1 \times 10^{12} \text{m}^{-3}$ and $3 \times 10^{20} \text{m}^{-3}$ respectively. If the hole concentration in A is $9 \times 10^{12} \text{m}^{-3}$, then the hole concentration in B at the same temperature will be
 (a) $3 \times 10^{12} \text{m}^{-3}$ (b) $7 \times 10^{12} \text{m}^{-3}$
 (c) $11 \times 10^{12} \text{m}^{-3}$ (d) $27 \times 10^{12} \text{m}^{-3}$
66. Which one of the following statements is not correct?
 (a) Vacuum can act as a dielectric material
 (b) Piezoelectric materials can act as transducers
 (c) Quartz crystal is a ferroelectric material
 (d) The dielectric constant of dielectrics depends on the frequency of the applied field
67. In which one of the following ways can the Hall voltage across an impurity semiconductor crystal be increased?
 (a) By increasing the thickness of the crystal
 (b) By increasing the concentration of impurity atoms in the crystal
 (c) By increasing the width of the crystal
 (d) By increasing the current flowing through the crystal
68. Which one of the following statements is correct?
 The application of the instrument in wrong manner in the procedure of measurement results in a/an
 (a) Systematic error (b) Random error
 (c) Gross error (d) Instrument error
69. Which one of the following statements correctly represents the systematic errors?
 (a) These errors can be calculated from the details of the instruments
 (b) These are the residual errors
 (c) These errors may occur under controlled conditions
 (d) These are the errors committed by the experimenters
70. Which one of the following statements is correct?
 The deflection of hot wire instrument depends on
 (a) r.m.s value of the ac current
 (b) r.m.s value of the ac voltage
 (c) Average value of the ac current
 (d) Average value of the ac voltage
71. Which one of the following materials is used in the fabrication of swamping resistance of a PMMC instrument?
 (a) Copper (b) Aluminum
 (c) Manganin (d) Tungsten
72. Which one of the following is basically a current sensitive instrument?
 (a) Permanent magnet moving coil instrument
 (b) Cathode ray oscilloscope
 (c) Electrostatic instrument
 (d) FET input electronic voltmeter
73. Which one of the following types of instruments can be used to determine the r.m.s value of ac voltage of high magnitude (10 kV) and of any wave shape?
 (a) Moving iron instruments
 (b) Dynamometer type instruments
 (c) Induction instruments
 (d) Electrostatic instruments
74. The battery cells in an electronic multimeter are required to measure which one of the following?
 (a) Resistance (b) Voltage
 (c) Current (d) Power
75. Low resistance from few ohms down to one micro ohm is measured using which one of the following instruments
 (a) Ohmmeter
 (b) A series type ohmmeter
 (c) A shunt type ohmmeter
 (d) A voltmeter and an ammeter
76. Which one of the following statements is correct?
 An electronic voltmeter is more reliable as compared to multimeter for measuring voltages across low impedance because
 (a) Its sensitivity is high
 (b) It offers high input impedance
 (c) It does not alter the measured voltage
 (d) Its sensitivity and input impedance are high and do not alter the measured value

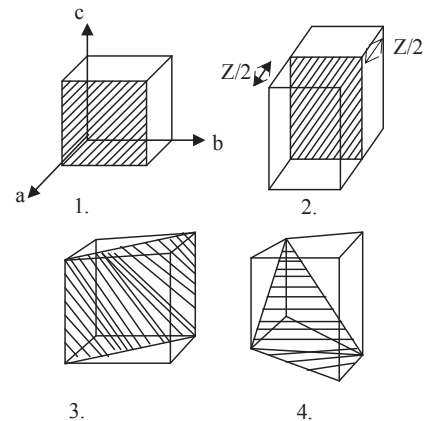
77. Which one of following statements is not correct?
 (a) Vacuum can act as a dielectric material
 (b) Piezoelectric materials can act as transducers
 (c) Quartz crystal is a ferroelectric material
 (d) The dielectric constant of dielectrics depends on the frequency of the applied field
78. Which one of the following definitions correctly represents a data acquisition system (DAS)?
 (a) DAS is a group of electronics devices that are connected to perform the measurement and quantization of electrical signals for digital processing
 (b) DAS is a group of devices that are connected to store different signals
 (c) DAS is a system to control a process
 (d) DAS is a signal conditioner
79. Which one of following thermocouples has the highest temperature measuring range?
 (a) Copper – constantan
 (b) Iron – Constantan
 (c) Alumel – Chromel
 (d) Platinum Rhodium – Platinum
80. When the temperature of a magnetic material is raised above the Curie point, it becomes
 (a) Diamagnetic (b) Paramagnetic
 (c) ferromagnetic (d) ferromagnetic
81. Soft iron is used in the manufacture of electromagnets because of its
 (a) High saturation magnetization only
 (b) Low retentivity only
 (c) Low coercive field only
 (d) High saturation magnetization, low retentivity and low coercive field
82. With increase in temperature, magnetic susceptibility of a ferromagnetic material will
 (a) Increase
 (b) Decrease
 (c) Increase initially and then decrease
 (d) Remain constant
83. The relative dielectric constant of solid dielectrics in the alternating field is
 (a) Maximum at the power frequencies and decreases to unity at frequencies in the ultraviolet range
 (b) Maximum at to power frequencies and decreases to zero at frequencies in the ultraviolet range
 (c) Unity at to power frequencies and increases to its maximum value at frequencies in the ultraviolet range
 (d) Independent of frequency variations
84. Width of energy bands depends on which of the following?
 (a) Temperature
 (b) Pressure

- (c) Relative freedom of electrons in the crystal
 (d) Mass of atom in the material

85. Which one of the following statements is not true for a p-type semiconductor?
 (a) Conduction is by the movement of holes in the valence band
 (b) Holes constitute the majority charge carriers
 (c) Fermi level lies closer to the conduction band between the conduction and valence bands
 (d) It is formed by adding an acceptor impurity to germanium

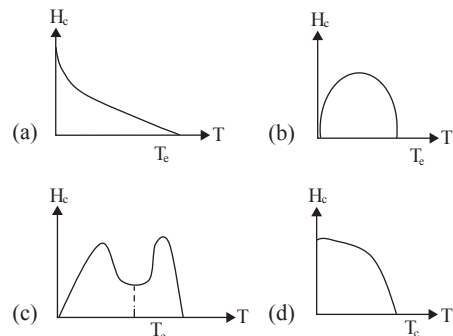
LEVEL 3

1. Consider the following crystallographic planes (shaded) using a cube of size z as shown in the diagram:

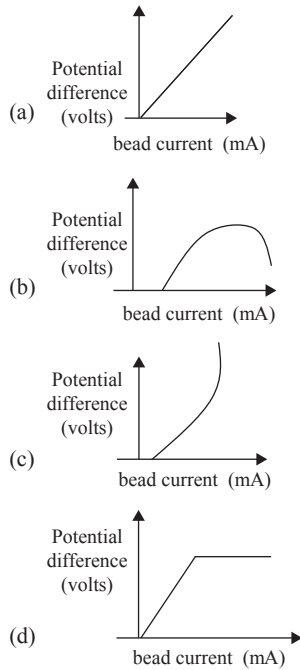


Which one of the following gives Miller indices of the above planes, in order?

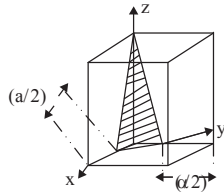
- (a) (110), (200), (100), (111)
 (b) (100), (200), (110), (111)
 (c) (111), (110), (200), (100)
 (d) (200), (111), (110), (100)
2. Which one of following correctly represents the variation of critical magnetic field (H_c) with temperature for a superconductor?



3. Which one of the following correctly depicts the $V-I$ characteristics of a typical bead thermistor?

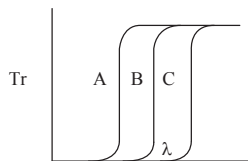


4. Each side of the cube shown below is of length a . What are the Miller indices of the shaded surface?



- (a) (100) (b) (123)
(c) (221) (d) $\left(\frac{1}{2} \frac{1}{2} 1\right)$

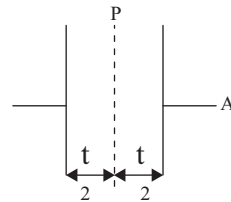
5. Photovoltaic devices may be made from various semiconductors as optical materials for which the transmission coefficient (Tr) is shown in the figure given below as a function of photon wavelength.



Which one of the following is the correct sequence of A , B and C pertaining to Ge, GaAs and Si, respectively?

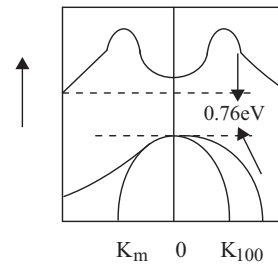
- (a) $A-B-C$ (b) $B-A-C$
(c) $C-A-B$ (d) $C-B-A$
6. A parallel plate capacitor of plate area A and plate separation ' t ' has a capacity C . If a metallic plate p of area A and

of negligible thickness is introduced in the capacitor at a distance $(t/2)$ from either of the two plates, as shown in the given figure, then the capacity of the capacitor will come



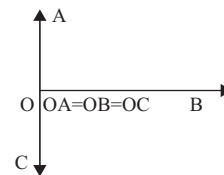
- (a) $C/2$ (b) C
(c) $2C$ (d) $4C$

7. The band structure shown in the given figure is that of



- (a) Gallium Arsenate (Ga As)
(b) Silicon (Si)
(c) Copper (Cu)
(d) Germanium (Ge)

8. In the figure below, A , B and C are equal charges. When a unit charge moves from ' C ' to ' O ', the force on the charge when it reaches will be



- (a) Zero
(b) A pull in the direction of A
(c) A pull in the direction of B
(d) None of the above

9. A solid specimen of dielectric has relative permittivity $\epsilon_r = 4.2$ and loss angle $\tan \delta = 0.001$ at 50 Hz frequency. If it is subjected to an electrical stress of 50 kV/cm, what is the heat generated in the specimen due to dielectric loss?

- (a) 291 W/cm³ (b) 5.82 mW/cm³
(c) 19.51 W/cm³ (d) 0.291 mW/cm³

10. The dipole moment per unit volume as a function of E in the case of an insulator is given by (symbols have the usual meaning)

- (a) $P = \epsilon_0 E (\epsilon_r - 1)$ (b) $P = \epsilon_0 E$
 (c) $P = \frac{E}{\epsilon_0 \epsilon_r}$ (d) $P = \frac{E}{\epsilon (\epsilon_r - 1)}$
11. The wavelength of light emitted by a Ga As laser is 8670×10^{-10} m. Given Plank's constant $= 6.626 \times 10^{-34}$ Js, velocity of light $= 2.998 \times 10^8$ ms⁻¹ and $1 \text{ eV} = 1.602 \times 10^{-19}$ J, the energy gap in Ga As is
 (a) 0.18 eV (b) 0.7 eV
 (c) 1.43 eV (d) 2.39 eV
12. A vacuum parallel plate capacitor is charged. The field between the plates is 2×10^4 v/m. If the space between the plates is filled with a material of relative dielectric constant of 10.0, then the value of the field in the dielectric will be
 (a) 2×10^3 V/m (b) $\frac{2}{\sqrt{10}} \times 10^{-4}$ V/m
 (c) $2 \times \sqrt{10} \times 10^4$ V/m (d) 2×10^5 V/m
13. Magnetic susceptibility of an ideal Type I superconductor in the superconductivity state is
 (a) $-\infty$ (b) -1
 (c) between 0 and -1 (d) zero
14. The electrical conductivity of metals is typically of the order of (in ohm⁻¹ m⁻¹)
 (a) 107 (b) 105
 (c) 10^{-4} (d) 10^{-6}
15. The resistance of a circuit is found by measuring current flowing and the power fed into the circuit. If the limiting error in the measurement of power and current are $\pm 1.5\%$ and $\pm 1.0\%$ respectively, the limiting error in the measurement of resistance will be
 (a) $\pm 1\%$ (b) $\pm 1.5\%$
 (c) $\pm 2.5\%$ (d) $\pm 3.5\%$
16. When n_e and n_h are the electron and hole densities, and μ_e and μ_h are the carrier mobilities, the Hall coefficient is positive when,
 (a) $n_h \mu_h > n_e \mu_e$ (b) $n_h \mu_h^2 > n_e \mu_e^2$
 (c) $n_h \mu_h < \mu_e$ (d) $n_h \mu_h^2 > n_e \mu_e^2$
17. When the time period of the applied voltage is much shorter than the relaxation time of a polarization process, the loss of angles δ is
 (a) zero (d) between 0 and 90°
 (c) 90° (d) greater than 90°
18. In a linear chain of atoms of interatomic distance ' T '; the first Brillouin zone occurs between wave numbers
 (a) $-\frac{\pi}{T}$ and $+\frac{\pi}{T}$ (b) $-\frac{2\pi}{T}$ and $+\frac{2\pi}{T}$
 (c) Zero and $\frac{2\pi}{T}$ (b) $-\frac{1}{T}$ and $+\frac{1}{T}$
19. If $E - E_F = 2kT$ (E_F is Fermi energy and ' k ', the Boltzmann's constant is 8.614×10^{-5} eV/K), then the probability that an electron occupies an energy level ' E ' is
 (a) 0.63 (d) 0.5
 (c) 0.27 (d) 0.12
20. The total iron loss in a transformer core at normal flux density was measured at 25 Hz and 50 Hz and was found to be 250 W and 800 W respectively. The hysteresis loss at 50 Hz would be
 (a) 100 W (b) 150 W
 (c) 200 W (d) 600 W
21. The Hall coefficient of a sample of silicon having 10^{22} arsenic atoms per m³ is
 (a) 3.49×10^{-3} m³/C (b) 6.25×10^{-4} m³/C
 (c) 1.37×10^{-4} m³/C (d) 9.44×10^{-5} m³/C
22. The isotope effect predicts that the superconducting transition temperature should be proportional to (M is the atomic mass)
 (a) M (b) $1/\sqrt{M}$
 (c) $1/M$ (d) $\sqrt{M}$
23. A small saw cut is made in a permanent magnet of toroidal shape. Which of the following are true for H_o if H_o is the magnetic field in the air-gap and H_i is that inside the magnet?
 1. $H_o < |H_i|$
 2. $H_o > |H_i|$
 3. H_o is in the same direction as H_i
 4. H_o and H_i are in opposite directions
 Select the correct answer using the codes given below
 (a) 1 and 2 (b) 1 and 4
 (c) 2 and 3 (d) 2 and 4
24. Silicon contains 5×10^{28} atoms per cubic metre. If it is doped with two parts per million of arsenic, then the electron density at room temperature will be approximately
 (a) 4×10^{23} m⁻³ (b) 10^{23} m⁻³
 (c) 2×10^6 m⁻³ (d) 10^4 m⁻³
25. The electron relaxation time of metal A is 2.7×10^{-4} sec, that of B is 1.35×10^{-4} sec. The ratio of resistivity of B to resistivity of A will be
 (a) 4.0 (b) 2.0
 (c) 0.5 (d) 0.25

ANSWER KEYS

LEVEL 1

1. (c)	2. (d)	3. (c)	4. (c)	5. (d)	6. (b)	7. (d)	8. (a)	9. (d)	10. (d)
11. (c)	12. (a)	13. (a)	14. (c)	15. (c)	16. (b)	17. (d)	18. (d)	19. (d)	20. (c)
21. (a)	22. (a)	23. (b)	24. (c)	25. (a)	26. (b)	27. (d)	28. (a)	29. (c)	30. (c)
31. (b)	32. (b)	33. (a)	34. (a)	35. (a)	36. (c)	37. (a)	38. (d)	39. (c)	40. (c)
41. (b)	42. (a)	43. (a)	44. (b)	45. (b)	46. (d)	47. (d)	48. (d)	49. (c)	50. (a)
51. (c)	52. (b)	53. (c)	54. (b)	55. (b)	56. (b)	57. (c)	58. (b)	59. (a)	60. (a)
61. (a)	62. (d)	63. (d)	64. (b)	65. (c)	66. (a)	67. (c)	68. (c)	69. (b)	70. (d)
71. (d)	72. (c)	73. (d)	74. (a)	75. (c)	76. (a)	77. (c)	78. (b)	79. (b)	80. (d)
81. (d)	82. (b)	83. (c)	84. (c)	85. (a)	86. (d)	87. (a)	88. (a)	89. (c)	90. (d)
91. (a)	92. (a)	93. (a)	94. (b)	95. (d)	96. (c)	97. (d)	98. (d)	99. (c)	100. (d)
101. (a)	102. (d)	103. (d)	104. (a)	105. (b)	106. (b)	107. (b)	108. (b)	109. (a)	110. (a)

LEVEL 2

1. (d)	2. (a)	3. (a)	4. (a)	5. (b)	6. (a)	7. (b)	8. (d)	9. (b)	10. (a)
11. (c)	12. (b)	13. (d)	14. (c)	15. (c)	16. (d)	17. (d)	18. (b)	19. (b)	20. (b)
21. (c)	22. (c)	23. (c)	24. (d)	25. (c)	26. (a)	27. (b)	28. (d)	29. (c)	30. (b)
31. (b)	32. (c)	33. (a)	34. (a)	35. (d)	36. (c)	37. (c)	38. (b)	39. (d)	40. (d)
41. (d)	42. (b)	43. (b)	44. (b)	45. (a)	46. (b)	47. (b)	48. (a)	49. (b)	50. (a)
51. (b)	52. (c)	53. (a)	54. (b)	55. (a)	56. (a)	57. (b)	58. (a)	59. (c)	60. (c)
61. (b)	62. (d)	63. (b)	64. (b)	65. (a)	66. (a)	67. (d)	68. (d)	69. (a)	70. (a)
71. (c)	72. (a)	73. (d)	74. (a)	75. (d)	76. (d)	77. (a)	78. (a)	79. (d)	80. (b)
81. (c)	82. (b)	83. (b)	84. (a)	85. (c)					

LEVEL 3

1. (b)	2. (d)	3. (d)	4. (c)	5. (c)	6. (b)	7. (a)	8. (d)	9. (d)	10. (a)
11. (c)	12. (a)	13. (b)	14. (d)	15. (d)	16. (b)	17. (a)	18. (a)	19. (d)	20. (c)
21. (b)	22. (c)	23. (c)	24. (b)	25. (b)					

PHYSICAL ELECTRONICS, ELECTRON DEVICES AND ICs

2.1 ELECTRONS AND HOLES IN SEMICONDUCTORS, CARRIER STATISTICS

Atomic Structure

- An atom consists of a nucleus of positive charge (Proton and Neutron) that contains all the mass. Electron revolves in a fixed orbit. Orbits have different energy levels and the farther an orbit from the nucleus, the higher the energy associated with that orbit.

$$\begin{aligned}\text{Energy of } n\text{th orbit} &= P.E + K.E \\ &= \frac{m.q^2}{8h^2 \epsilon_o} \cdot \frac{1}{n^2} \text{ joule} \\ &= \frac{-13.6}{n^2} \text{ eV}\end{aligned}$$

Fermi-Dirac Function

Fermi Dirac function $f(E)$ gives the probability that a quantum state with energy E is occupied by an electron.

$$f(E) = \frac{1}{1 + e^{(E-E_f)}}$$

Fermi level E_f represents the energy state with 50 per cent probability of being filled if no forbidden band exists.

At $T = 0^\circ \text{K}$, if $E \gg E_f$ then $f(E) = 0$

Energy Band

- The coupling of shell electrons results in a band of closely spaced energy state.

- The electrons of outer most orbit in crystal structure form a band called **valance band**.
- The electrons, which are free from their parent atoms, possess higher energy and lie in **conduction band**.
- The region containing no quantum state between valance and conduction band is called Forbidden Energy Gap.
- On the basis of Band Theory and Forbidden Energy Gap, elements are classified in to three groups:
 - (a) Insulator $E_g > 5 \text{ eV}$
 - (b) Semi conductor $0.1 \text{ eV} < E_g < 5 \text{ eV}$
 - (c) Conductor $E_g < 0.1 \text{ eV}$.

Semiconductors

- Semiconductors are those elements that behave as insulators at low temperature but cause conduction by electron motion at room temperature.
- Semiconductor elements are crystalline in nature and are in the diamond lattice structure.
- In general, group-IV elements, that is tetravalent elements, are considered semiconductors, but it is not true.
- Carbon $E_g = 7 \text{ eV} \rightarrow$ Insulator at room temperature.

$$\left. \begin{array}{ll} \text{Silicon} & E_g = 1.1 \text{ eV} \\ \text{Germanium} & E_g = 1.72 \text{ eV} \end{array} \right\} \text{ Semiconductor}$$

$$\left. \begin{array}{l} \text{Tin} \\ \text{Lead} \end{array} \right\} E_g = 0.1 \text{ eV} \rightarrow \text{Conductor.}$$

- Certain compounds of group III–V behave as semiconductors i.e., GaAs, GaAsP, GaAs is used in microwave Gun Oscillator.
- Semiconductors form the covalent bond by sharing two electrons of opposite spins, one from each atom.

2.2 ■ Physical Electronics, Electron Devices and ICs

- Ge and Si have Miller Indices of (111) lattice.
- GaAs has Miller Indices of (110) lattice.
- Conductivity:
 1. Due to electron $\sigma_n = \mu_e n_e q$
 2. Due to hole $\sigma_p = \mu_p n_p q$
- Total conductivity of semiconductor material.
Exclusion principle is not applicable.
 $\sigma = (\mu_e n_e + \mu_p n_p) q$

Intrinsic Carrier Concentration

$$n_i^2 = AT^3 e^{\left(\frac{-E_g}{KT}\right)}$$

Drift Velocity

$$V_d = \mu E$$

- Electrons in Germanium move three times faster than Silicon, making Germanium suitable for high frequency application $3\mu_s = \mu_g$.
- Electron-hole mobility ratio in Ge is 2:1 and in Silicon is 2.8:1, In general, $\mu_e = 3\mu_p$.
- Conductivity of Germanium increases by 6% per degree rise in temperature.
- In intrinsic semiconductor $n = p = n_i$
 $np = n_i^2 \rightarrow$ **mass action law**.
 $\sigma_i = n_i (\mu_n + \mu_p) q$
 Conduction current density
 $J_i = q n_i (\mu_n + \mu_p) E = \sigma E$.
- Intrinsic semiconductors are not used for fabricating an electronic device since the conductivity can not be controlled.

Carrier Concentration in Intrinsic Semiconductors

The concentration of free electrons n and the concentration of holes p in a semiconductor are given by

$$dn = N(E) f(E) dE$$

E is in eV

where, dn is the number of conduction electrons per cubic metre whose energy lies between E and $E + dE$.

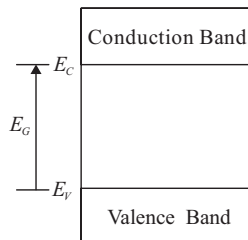


Fig. 2.1

In a semiconductor, the lowest energy in a conduction band is E_c

$$N_E = \gamma (E - E_c)^{1/2} \text{ for } E > E_c$$

$$\text{Fermi function } F(E) = \frac{1}{1 + e^{\left(\frac{E - E_F}{kT}\right)}}$$

In case of impure semiconductors, the Fermi level does not lie in the center of valence and conduction band.

Extrinsic Semiconductor

- To control the conductivity of semiconductor, group III or V elements are added in the parent material which makes it extrinsic semiconductor.
- Group-III elements, i.e., boron, aluminum, gallium, indium added makes P type semiconductor. GP-III Tellurium is not used.
- GP-V elements, i.e., Antimony, phosphorus, Arsenic, Bismuth addition makes N -type semiconductor, GP-V Nitrogen is not used.
- For N the $n_N \cdot p_N = n_i^2$; $n_N = N_D$
 Therefore, $p_N = \frac{n_i^2}{N_D}$
- For P type $n_P \cdot p_P = n_i^2$; $p_P = N_A$
 Therefore, $n_P = \frac{n_i^2}{N_A}$
- The Intrinsic receptivity of a semiconductor is given by
 $= A e^{\left(\frac{E_g}{KT}\right)}$
 A = Coefficient verifying slightly with temperature.
- **The Energy gap E_g** of Silicon decreases with temperature at the rate of 3.6×10^{-4} eV/k
 $E_g(T) = 1.21 - 3.6 \times 10^{-4} T$ for Si
 $E_g(T) = 0.785 - 2.23 \times 10^{-4} T$ for Ge.
- As the Energy gap E_g of Si is more than Ge, Si can be operated at a high temperature.

2.2 MECHANISM OF CURRENT FLOW IN A SEMICONDUCTOR

Flow of Current in a Semiconductor

It is due to two mechanisms:

Drift Current is due to applied electric field.

$$J_n = q n \mu_n E; J_p = q p \mu_p E,$$

Diffusion current is due to diffusion of carrier from a region of high charge density region to low charge density i.e., concentration.

$$\text{Gradient of charge density } J_n = q D_n \frac{dn}{dx}; J_p = -q D_p \frac{dp}{dx}$$

Total Current

- (a) Due to electron $J_n = q n \mu_n E + q D_n \frac{dn}{dx}$
- (b) Due to hole $J_p = q p \mu_p E - q D_p \frac{dp}{dx}$

Fermi Level

It is the energy which any electron possess at 0° Kelvin.

- (a) For Intrinsic Semiconductor $E_{FI} = \frac{E_v + E_c}{2}$

This is the energy level which lies exactly in the middle of valance and conduction band.

- (b) For *P*-type semiconductor

$$E_{FP} = E_v + V_T \ln \left(\frac{N_v}{N_A} \right);$$

$$n_p = N_c N_v e^{\left(\frac{E_v - E_c}{KT} \right)}$$

$$\text{where, } V_T = \frac{KT}{q} = \frac{T}{11600}$$

at room temperature $T = 300 \text{ K}$; $V_T = 26 \text{ mV}$

E_v = Valance band energy

N_v = Carrier concentration in valance band

N_A = Acceptor impurity concentration

E_c = Lowest energy of conduction band

E_v = Maximum energy of valance band

As T increases the E_{FP} goes away from the conduction band.

If $N_v = N_A$

Then $E_{FP} = E_v$

- (c) For *N* type semiconductor

$$E_{FN} = E_c - V_T \ln [N_c/N_D]$$

As T increases, the E_{FN} moves away from conduction band towards valance band.

$$J_n = q D_n \frac{dn}{dx}; \quad J_p = -q D_p \frac{dp}{dx}$$

If $N_c = N_v$, $E_{FN} = E_c$

For *n* type material

$$E_F = E_c - kT \ln \left(\frac{N_c}{N_D} \right)$$

$N_D \rightarrow$ doner concentration

For *p*-type material

$$E_F = E_v + kT \ln \left(\frac{N_v}{N_A} \right)$$

$N_A \rightarrow$ acceptor concentration

Band gap for the semiconductor is given by

$$E_G = kT \ln \left(\frac{N_c N_v}{n_i^2} \right)$$

Effect of Temperature on Fermi Level

- For *N*-type semiconductor, Fermi level goes down with an increase in temperature and with more increase in temperature, it will come at the centre of forbidden energy gap. The conclusion is that, **at higher temperature, *N*-type semiconductor behaves like an insulation.**
- For *P*-type semiconductor, Fermi level goes up with an increase in temperature and with more increase in

temperature, it will come at the center of forbidden energy gap. Again conclusion is that, **at higher temperature, *p*-type semiconductors behave like an insulator.**

Effect of Doping of Fermi Level

- With *N*-type doping, Fermi level goes up towards conduction band.
- With *P*-type doping, Fermi level goes down towards valance band.

Mobility

It is defined as the drift velocity of the charge carrier per unit electric field.

$$\mu = [V_d/E]; \quad V_d = \mu E$$

- As the temperature increases, mobility decreases because the number of carrier increases with increased collision causing scattering.
- For $E < 10^3 \text{ V/cm}$, μ is constant, and for $E > 10^4 \text{ V/cm}$, μ is inversely proportional to E .
- Einstein relation $D = \mu V_T$
where, D = Diffusion Constant.

2.3 HALL EFFECT

If a specimen (carrying a current I , metal or semiconductor) is placed in a transverse magnetic field B , and electric field E is induced in the direction perpendicular field B , this is Hall effect.

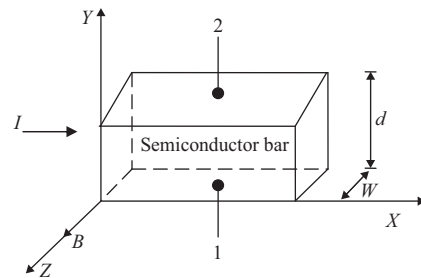


Fig. 2.2

The hall effect is very weak in metal, but is large in semiconductor.

2.4 JUNCTION THEORY

PN Junction

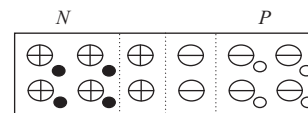


Fig. 2.3

2.4 ■ Physical Electronics, Electron Devices and ICs

- PN Junction is formed on a single crystal of semiconductor like Ge or Si by doped acceptor impurity on one side and donor impurity on the other side.
- Since *P*-side has large hole as compared to electron and *N*-side has large electron as compared to hole, so due to the difference in concentration, diffusion takes place, i.e., hole diffuses to *N*-side and electron diffuses to *P*-side.
- Depletion region is completely free from any mobile charge. It behaves just like capacitor, which is controlled by applied voltage at *P* and *N* sides.
- Forward bias causes depletion region to shrink, so it increases the value of the capacitor.
- Total depletion region width

$$W = W_n + W_p$$

$$N_D W_n = N_A W_p$$

It means for highly doped region, the depletion region is less in that side.

- Barrier potential or build-in potential

$$V_B = V_T \ln \left(\frac{N_A \cdot N_D}{n_i^2} \right) = \frac{KT}{q} \ln \left(\frac{N_A \cdot N_D}{n_i^2} \right)$$

- Current flow in PN junction diode

$$= I_o \left(e^{\frac{V}{nV_T}} - 1 \right)$$

where, I_o = Reverse saturation current

n = Factor due to charge generation and recombination

$n = 1$ for Ge

$= 2$ for Si

- I_o doubles for every 10°C rise in temperature

$$I'_o = I_o 2^{((T'-T)/10)}$$

- Diode dynamic resistance

$$r = \frac{dV}{dI} = \frac{1}{dI/dV} = 1/\text{Slop of characteristic of diode}$$

$$= \frac{nV_T}{I} = \frac{26 (mV)}{I (mA)}; n=1$$

$$I_o = q \left(n_p \frac{L_n}{\tau_n} + p_n \frac{L_p}{\tau_p} \right)$$

Capacitance in PN Junction Diode

The depletion region denotes a parallel plate capacitor since the total charge on the two sides of the depletion region is equal but opposite.

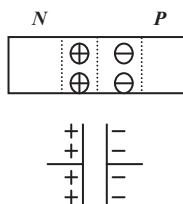


Fig. 2.4

$$C = \frac{\epsilon A}{d} = \frac{\epsilon A}{W}$$

where, ϵ = permittivity of medium

A = cross section area

$d = W$ = Total width of depletion region

$$= W_n + W_p$$

Capacitance is of Two Types

Transition Capacitance C_T arises due to reverse bias applied and due to majority charge carrier.

$$C_T(V_r) = \frac{C(o)}{1 + [V_r/V_T]^n}$$

V_r = Reverse bias voltage

$C(o)$ = Capacitance at zero bias

$n = [1/2]$ for step graded/Abrupt junction

$= [1/3]$ for diffused/linearly graded junction

Finally,

$$C_T = K_1 [V]^{-1/2} : \text{for abrupt junction}$$

$$= K_2 V^{-1/3} : \text{for linearly graded function}$$

$$W_B = K_1 [V_j]^{1/2} : \text{for abrupt junction}$$

$$= K_2 [V_j]^{1/3} : \text{for linearly graded junction}$$

Diffusion Capacitance C_D exists for forward bias and is important for minority charge carrier

$$C_D = \frac{\tau_n}{r_n} + \frac{\tau_p}{r_p}$$

where, τ = Life time

r = Dynamic resistance of region.

- Diffusion capacitance increases rapidly with forward bias, i.e., $C_D \propto I$.
- The value of C_D is of the order of several pF and hence it is important when high frequency circuit for transistor is derived.
- Voltage variable diode capacitor is called *Varactor*, Varicap or Volta cap. They are used in frequency modulation circuits.

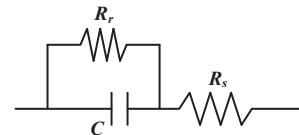


Fig. 2.5

$$L = \sqrt{D\tau}$$

The Einstein relation

$$\frac{D}{\mu} = V_T = \frac{KT}{q}$$

2.5 DIFFERENT TYPES OF DIODES AND THEIR CHARACTERISTICS

Diode

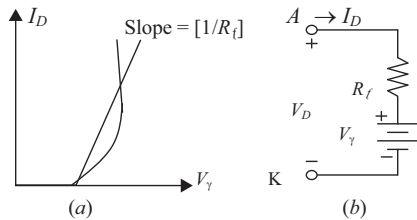


Fig. 2.6 (a) Piecewise linear diode forward characteristic (b) Diode model for forward bias.

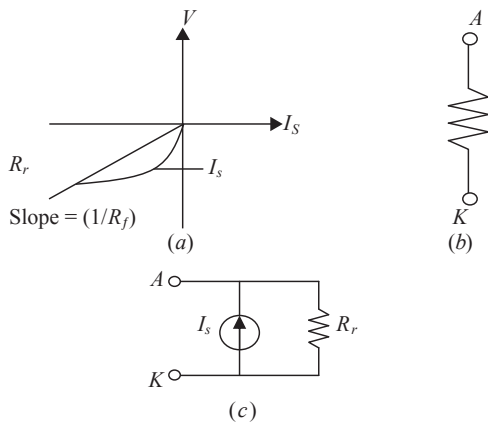


Fig. 2.7 (a) Piecewise linear reverse characteristic of diode (b) Diode model based on piecewise linear representation. (c) Model to include surface leakage

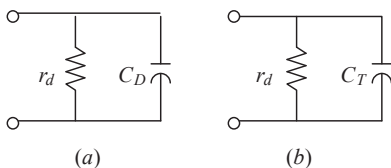


Fig. 2.8 Small-signal diode models for (a) Forward bias (b) Reverse bias

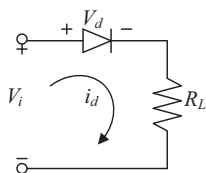


Fig. 2.9 (a) Diode-resistor circuit

2.6 ZENER DIODE

It is a PN junction diode with heavy doping operated under reverse bias condition and for voltage $> V_g$ (Breakdown Voltage).

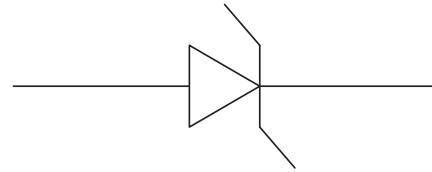


Fig. 2.10

Works on Two Breakdown Phenomena

Zener breakdown and Avalanche breakdown.

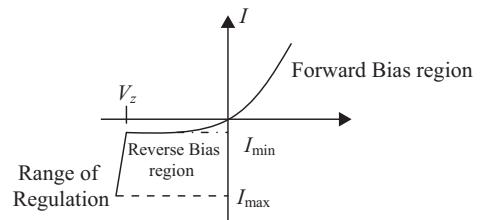


Fig. 2.11 V-I characteristic

Zener Breakdown

This device can be utilized as a voltage regulator since the voltage across it remains constant irrespective of current variation through it.

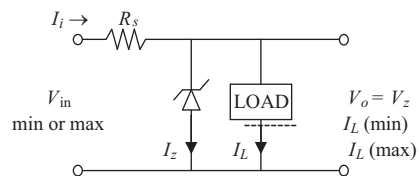


Fig. 2.12

Avalanche Breakdown

1. This breakdown occurs in PN junction diode with reverse bias applied.
2. The doping is much greater than that used in the ordinary PN junction diode but is smaller than that of a diode in which Zener breakdown occurs, i.e., $D_{\text{Zener}} > D_{\text{avalanche}} > D_{\text{ordinary}}$.

2.6 ■ Physical Electronics, Electron Devices and ICs

- The reverse bias voltage applied is relatively higher of the order of 8 to 10 V depending upon doping.

Comparison

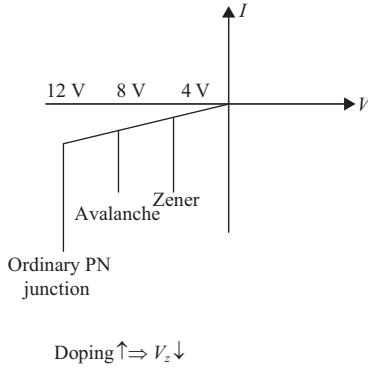


Fig. 2.13

2.7 TUNNEL DIODE/ESAKI DIODE

- If the concentration of impurity atom is greatly increased from its normal value, 1 part in 10^8 to 1 part in 10^3 , device characteristics are totally changed.
- It is fabricated from Ge or GaAs.
- The width of junction barrier varies as $1/\sqrt{n}$ where, n = impurity concentration, due to high doping thin barrier result. There is great probability that an electron will penetrate through the barrier even when the barrier potential is not able to prevent it. This is called tunneling and these high impurity density diodes are called tunnel diodes.
- Tunnel diode is an excellent conductor in the reverse direction too.
- Its reverse breakdown voltage is very small, almost approaching zero.

2.8 BIPOLAR JUNCTION TRANSISTOR

BJT: Bipolar Junction Transistor

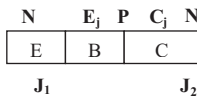


Fig. 2.14

Collector region width is maximum

- To collect maximum number of charge carrier.
- To reduce heat dissipation (per unit area surface).

Depletion layer in collector junction base side is maximum. In emitter junction, emitter side is minimum.

Biasing and application

Input Jn J ₁ (EB J _n)	Output Jn J ₂ (CB J _n)	Region in Which BJT works	Application
FB	RB	Active	Amplifier
FB	FB	Saturation	BJT is ON or OFF
RB	RB	Cut off	OFF
RB	FB	Inverted (Active)	Amplifier with decreased gain $\alpha_P \beta_I$

- For normal biasing (i.e., emitter junction FB and collector junction RB) the emitter junction has low resistance.

Early Effect

For active region operation of transistor collector base, region is reversed biased. Due to reverse bias, the depletion width in base region increases, which causes effective width of base to decrease. This effect is known as *early effect* base width modulation.

If the reverse bias V_{cs} is increased beyond a point, breakdown may occur as width of base becomes zero, and this phenomenon is called *punch through*.

On the basis of the considerations in the preceding paragraph, we construct the Ebers-Moll model in the below figure. The two back to back diodes (whose cathodes are connected) represent the junctions of the bipolar transistor, whereas the two controlled sources indicate the coupling between junctions.

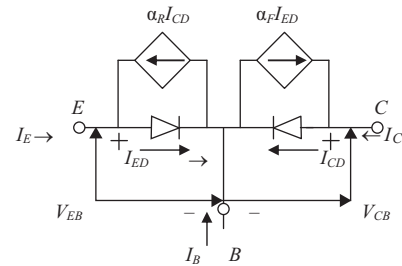


Fig. 2.15 Large-signal (Ebers-Moll) representation of a PNP transistor

The current I_{ED} and I_{CD} are related to V_{EB} and V_{CB} by the diode volt ampere relation given in the equation. Thus, the I_E and I_C can be expressed in terms of the two diodes currents as

$$I_E = I_{ED} - \alpha_R I_{CD}$$

$$= I_{ES} \left[\left(e^{V_{EB}/V_T} \right) - 1 \right] - \alpha_R I_{CS} \left(e^{V_{CB}/V_T} \right)$$

$$I_C = -\alpha_F I_{ED} + I_{CD}$$

$$= -\alpha_F I_{ES} \left(e^{V_{EB}/V_T} - 1 \right) + I_{CS} \left(e^{V_{CB}/V_T} - 1 \right)$$

The relationships expressed in the above two equations are known as the Ebers-Moll equations.

The quantities I_{ES} and I_{CS} in the above equation are reverse saturation currents of emitter base and collector base junction, respectively. The parameter α_F and α_R are each less than unity as not all the current from one diode is (coupled) to the other junction. The subscript refers to forward (F) transmission from emitter to collector and reverse (R) transmission from collector to emitter.

$$\alpha_F I_{ES} = \alpha_R I_{CS} \text{ and } I_B = -(I_E + I_C)$$

$$I_E = -I_{ES} (e^{V_{EB}/V_T} - 1) + \alpha_R I_{CS} (e^{V_{CB}/V_T} - 1)$$

$$I_C = \alpha_F I_{ES} (e^{V_{EB}/V_T} - 1) - I_{CS} (e^{V_{CB}/V_T} - 1)$$

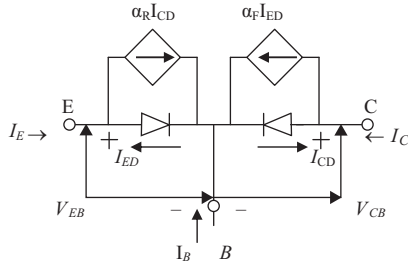


Fig. 2.16 Large-signal representation of a NPN transistor

Note: For a P channel FET, the bar is a P type semiconductor and gate is doped by n^+ donor impurity.

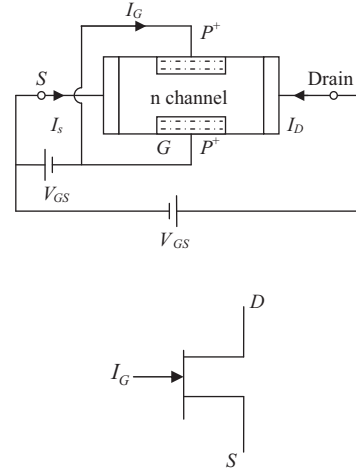


Fig. 2.17

Note: For a P channel FET, the bar is a P type semiconductor and gate is doped by n^+ donor impurity.

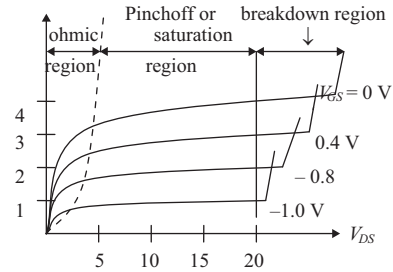


Fig. 2.18 N-channel FET characteristic

2.9 FIELD EFFECT TRANSISTOR

Two Types: n Channel and p Channel

It consists of a semiconductor block which is n type for n channel and p type for p channel. On both sides of n block acceptor impurities p are heavily doped by allowing or by diffusion. The region is called the gate. Ohmic contacts are attached to the either ends of the n -block. One end is called source and the other is called drain. The np region between source and gate is reverse biased. In the vicinity of np junction, there is diffusion of majority carriers, electrons and holes, leaving uncovered immobile positive and negative ions. When RB is applied, the space charge width increases uncovering more ions, until the space charge region from the two ends meets the n type region between the two (P^+) gates. It is called n channel, and when a positive voltage is applied between drain and source, there is a current flow in the channel of majority carriers (electrons). When a reverse bias is applied between the gate and source, constriction of the channel takes place by widening of the space charge depletion region, controlling the flow of electrons to the drain.

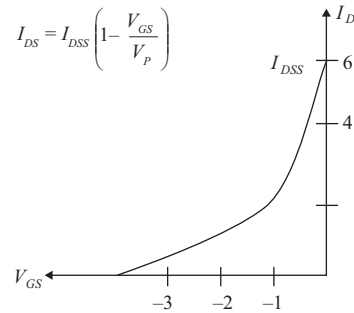


Fig. 2.19 FET Transfer characteristic

1. Drain resistance $r_d = \left. \frac{V_{DS}}{I_D} \right|_{V_{GS}=\text{Constant}}$

Output resistance of FET is evaluated in a constant drain current region of $V_{DS} - I_D$ curve. It is of the order of 10 to 20 k Ω s.

2. Trans conductance $g_m = \left. \frac{I_D}{V_{GS}} \right|_{V_{DS}=\text{Constant}}$

It will be of the order of 2 k to 6 k micromhos.

3. Amplification factor $\mu = g_m r_d$.

4. $= \frac{V_{DS}}{I_D} \times \frac{I_D}{V_{GS}} = \frac{V_{DS}}{V_{GS}}$, It ranges from 40 to 100.

5. Input resistance $r_{GS} = \frac{eN_D a^2}{2\epsilon}$

It is of the order of hundreds of megaohms. FET is a high impedance device.

Various Relationship FET

Pinch-off voltage $V_p = \frac{eN_D a^2}{2\epsilon}$

2a → Width of channel without any gates bias.

2b → Width of channel after bias.

$$b = a \left[1 - \left(\frac{V_{GS}}{V_p} \right)^{1/2} \right]; \text{ when } V_{GS} = 0, b = a$$

If $w \rightarrow$ channel dimension perpendicular to b direction

Drain current $I_D = AqN_D\mu_n E$

$$= 2bwq N_D\mu_n \frac{V_{DS}}{L}$$

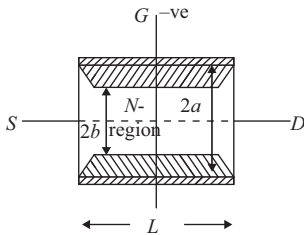


Fig 2.20

Substituting 'b'

$$I_D = \frac{2awqN_D\mu_n}{L} \left[1 - \left(\frac{V_{GS}}{V_p} \right)^{1/2} \right] V_{DS}$$

The ON resistance $r_d = \frac{V_{ds}}{I_d}$

$$r_{d \cdot ON} = \frac{L}{2awqN_D\mu_n} \text{ for } V_{GS} = 0$$

Transfer Characteristics

In the amplifier application, the FET is almost used in the region beyond pinch-off (also called the constant-saturation region).

$$I_{DS} = I_{DSS} \left(1 - \frac{V_{GS}}{V_p} \right)^2$$

Trans-conductance:

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}}$$

Relation between g_m , I_{DSS} and I_{DS}

$$I_{DS} = I_{DSS} \left(1 - \frac{V_{GS}}{V_p} \right)^2 \quad (1)$$

$$\frac{\partial I_{DS}}{\partial V_{GS}} = I_{DSS} 2 \left(1 - \frac{V_{GS}}{V_p} \right) \left(\frac{-1}{V_p} \right)$$

$$g_m = \left(\frac{-2I_{DSS}}{V_p} \right) \left(1 - \frac{V_{GS}}{V_p} \right) \quad (2)$$

g_{mo} = It is value of g_m for $V_{GS} = 0$ and given by

$$g_{mo} = \left(\frac{-2I_{GS}}{V_p} \right) \quad (3)$$

now $g_m = g_{mo} \left(1 - \frac{I_{DS}}{I_{DSS}} \right) \quad (4)$

From equation (1)

$$\left(1 - \frac{V_{GS}}{V_p} \right) = \sqrt{\frac{I_{DS}}{I_{DSS}}} \quad (5)$$

From equations (2) and (5)

From the transfer characteristic we have

$$g_m = \frac{-2I_{DSS}}{V_p} \sqrt{\frac{I_{DS}}{I_{DSS}}}$$

$$= \frac{-2}{V_p} \sqrt{I_{DS} \cdot I_{DSS}}$$

$$|g_m| = \frac{2}{|V_p|} \sqrt{I_{DS} \cdot I_{DSS}}$$

2.10 MOSFET

The real name of MOSFET is IG FET i.e., insulated gate field effect transistor. The gate insulated from the substrate by an oxide layer.

In the FET, the metal and channel with dielectric in between form a parallel plate capacitor giving rise to a high input impedance of (10^{10}) to (10^{15}) ohms, and this is the major difference from JFET. There are two types of MOSFET-enhancement and depletion type.

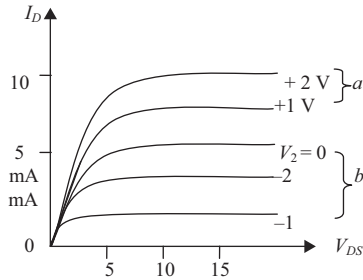


Fig. 2.21(a) Depletion MOSFET Characteristic

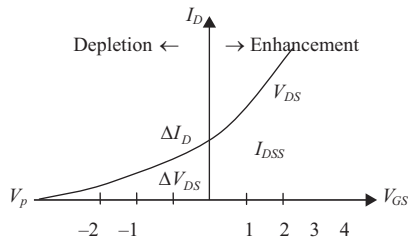


Fig. 2.21(b) Depletion N-MOSFET transfer characteristic

$$gm = \left. \frac{\Delta I_D}{\Delta V_{GS}} \right|_{V_{DS}=\text{const}}$$

Enhancement MOSFET

No channel is diffused in the P substrate. So, when a positive voltage is applied to the gate, the minority carriers are the P substrate, electrons are drawn towards the dielectric and this forms an effective channel. As the positive voltage on the gate is increased, conductivity increases leading to higher drain current as the negative charge carriers are increased.

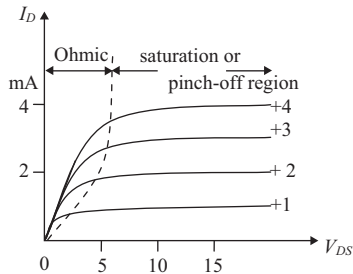


Fig. 2.22 (a) Enhancement NMOS FET characteristics

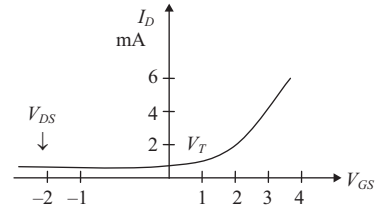


Fig. 2.22 (b) Transfer characteristic of N-channel E-MOSFET

- We note from the transfer characteristics that a threshold voltage V_{GST} is required for drain current to flow. Without gate voltage, a small current of nano-ampere I_D flows in the drain.
- The electric field produced by the gate voltage is largest near the source and least near the drain.
- For pinch-off $V_{PDS} = V_{GS} - V_T$

Typical values for JFET and MOSFET

Parametre	JFET	MOSFET
Input resistance r_{gs}	$> 10^9 \Omega$	$> 10^{13} \Omega$
Transconductance $r_d (\mu \text{ ohm})$	1 K to 2.5 K	1 K to 20 K
Drain resistance $r_d (\text{ohm})$	0.1 M to 1 M	1 K to 50 K
Revere current I_{GSS}	0.1 to 10 nA	0.1 to 10 pA
Capacitance $C(G \text{ to } D)$	1 to 4 pF	0.005 to 1 pF

For D-MOSFET

Characteristics are similar to FET

For E-MOSFET

$$V_{DS \text{ sat}} = V_{GS} - V_T$$

For $V_{GS} \ll V_T$, the drain current of an enhancement type MOSFET is 0 mA.

For levels of $V_{GS} > V_T$, the drain current is related to the applied gate-to-source voltage by the following nonlinear relationship

$$I_D = K(V_{GS} - V_T)^2$$

where, $K \rightarrow$ constant that is a function of the construction of the device, the value of K can be determined from

$$K = \frac{I_{D(on)}}{(V_{GS(on)} - V_T)^2}$$

$I_{D(on)}$ and $V_{GS(on)}$ are the values for each at a particular point on the characteristic of the device.

BJT	FET
1. High voltage gain	Low voltage gain
2. Low current gain	High current gain
3. Low input and output impedance	High input and output impedance
4. Medium noise generation	Low noise generation
5. (Gain × Band-width) high	(Gain × Band-width) medium
6. Current source	Voltage controlled

2.11 LED

LEDs are special diodes that exhibit light emission when connected in a circuit. The light is product by a solid state process called **electro luminescence**. Electro luminescence is the radiative recombination of electrons and holes under the effect of current across a p-n junction and the thereby generation of radiations.

Such an affect is observed in direct band gap materials such as GaAs. GaAs where under forward bias, the recombination of the electron hole pairs injected into the depletion region causes the emission of electromagnetic radiation.

When a sufficient forward bias voltage is applied to p-n region, these electrons recombine with the excess holes. This recombination generates a quantum of electromagnetic energy which is emitted as a photon of light.

The frequency of generated light depends upon the semiconductor material.

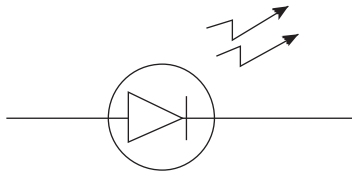


Fig. 2.23 Electric symbol

- The energy (E) of light emitted by an LED is related to the electric charge of an electron and the voltage required (V) to light the LED.
- Indirect $GaAs_{1-x}P_x$ doped with nitrogen can be used in LEDs with light output in yellow to green portions of the spectrum.
- GaAs, I_nP and mixed alloys of these compounds generate light in the infrared region.
- AlGap is useful for yellow and green wavelengths,
- GaN is a strong emitter of blue light.

2.12 PIN DIODE

Used as microwave switches with improved switching time.

$P+$	I or π	$N+$

π -high resistive P layer
 I -high resistive N layer

- When the reverse bias is applied the depletion region becomes thicker until the entire π layer is swept free of mobile carriers.
- The applied reverse bias, which swept the π region is termed as swept out voltage.
- The conductance of the device is determined by density of charge in the I region and its thickness whereas carrier life time τ determines its low frequency limit for useful operation.

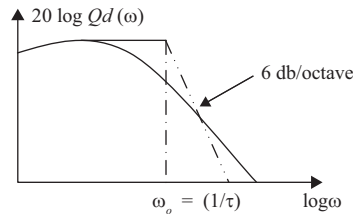


Fig. 2.24

- At frequency $f < f_o$, there is no change in stored energy in the PIN diode, it behaves as ordinary diode.
- At $f > f_o$, the charge decreases by 6 dB/octave and diode behaves as pure resistance whose value can be controlled by dc or low frequency signal.

2.13 PHOTO DIODE

It is a reverse bias semiconductor diode in which the electron hole pairs are produced in or near the depletion region. As a result of high electric field existence in the depletion region, the carriers generated by incident light separate quickly into the majority regions before they recombine. Thus most of electro generated pairs contribute to the photo current.

Dark current is as low as reverse saturation current.

Avalanche Photo Diodes are operated at high reverse bias voltage, such that avalanche multiplication takes place. Their internal gain is 10^4 and response time 0.1 ns.

Photo Devices

The amount of absorption of light depends upon the frequency of the incident light and the intrinsic semiconductor material.

Energy carried by a photon, $E = hf$

Band energy $= E_G$

When $hf \gg E_G$, then sharp rise in absorption takes place.

- When the photon energy $E = hf$ becomes laser, the E_G electron hole pairs are created by absorbing light and heroics conduction of current is possible.
- In a semiconductor, E_G decreases with rise in temperature.

- When hf is sufficiently increased, then electrons are freed from the solid by direct transition from the valance band to vacuum. This is called photo electric effect.
- Frequency which creates electron hole pair for Si, Ge and GaAs is in infrared region.

2.14 AVALANCHE PHOTODIODES

They are reverse biased pn junction exposed to incident light, the photons impacting the junction cause covalent bonds to break. And thus electrons-hole pairs are generated in depletion layer. The electric field in the depletion region sweeps the liberated charge carriers resulting in a photo current, which is proportional to the intensity of light.

Photodiodes are generally fabricated using GaAs.

The quantum efficiency of optical power P_{opt} and photon energy $h\nu$ is

$$n = \frac{I_{ph}}{q} \left(\frac{h\nu}{P_{opt}} \right)$$

Where,

$\frac{I_{ph}}{q}$ is the coverage number of electron hole pairs across the junction photo diode. Current is due to minority carriers in the depletion region.

The diode equivalent circuit for a photodiode is:

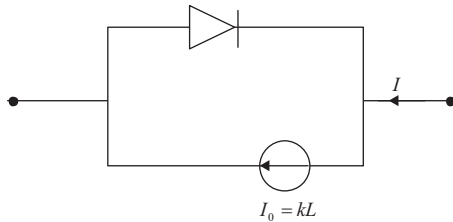


Fig. 2.25

Diode acts in parallel with current and source due to light intensity $I_0 = kL$ (L is flux in lumens).

2.15 BASICS OF PHOTO ELECTRONICS

Lasers

Laser – Light amplification by stimulated emission of radiation.

Lasers are a source of highly directional monochromatic, coherent light source. The light from laser can be continuous beam of low to medium power or short burst of intense light of high power.

Stimulated emission of radiation describes how lasers are generated. Basically, there are two modes of radiation emission due to electron movement from higher to lower energy state:

1. Spontaneous emission
2. Stimulated emission

In spontaneous emission the rates at which electrons fall from higher energy level E_2 to a lower energy level E_1 is proportional to the number of electrons remaining in E_2 . Thus we can expect an exponential emptying of electrons in energy level E_2 .

An electron can also be stimulated to fall to a lower level of energy and emit a photon in a very short time. The stimulus is provided by photons of proper wavelength.

The rate of stimulated emission is proportional to the number of electrons n_2 in energy state E_2 and the energy density of stimulating field $\rho(\nu_{12})$

$$r_{stimulated} = B_{21}n_2\rho(\nu_{12})$$

Where, B_{21} is proportionality factor.

Rate of spontaneous emission is proportional to the number of electrons in energy state E_2 i.e., n_2

Rate of absorption of photons by electrons in E_1 is proportional to the energy density of photon field $\rho(\nu_{12})$ and the number of electrons n_1 in energy state E_1 .

Under steady state.

$$\begin{matrix} \text{Absorption Rate} & = & \text{Spontaneous} & + & \text{Stimulated} \\ \text{Emission Rate} & & \text{Emission Rate} & & \text{Emission Rate} \end{matrix}$$

$$B_{12}n_1\rho(\nu_{12}) = A_{21}n_2 + B_{21}n_2\rho(\nu_{12})$$

This equation was given by Einstein and the coefficients A , B_{12} and B_{21} are called Einsteins coefficients.

At equilibrium, the ratio of stimulated to spontaneous emission rates is generally small.

In the presence of a photon field.

$$\begin{aligned} \frac{\text{Stimulated emission rate}}{\text{Spontaneous emission rate}} &= \frac{B_{21}n_2\rho(\nu_{12})}{A_{21}n_2} \\ &= \frac{B_{21}}{A_{21}}\rho(\nu_{12}) \end{aligned}$$

$$\text{Also, } \frac{\text{Stimulated emission rate}}{\text{Absorption emission rate}} = \frac{B_{21}}{B_{12}} = \frac{n_2}{n_1}$$

First ratio can be maximized by having a large photon field density $\rho(\nu_{12})$.

In lasers, this is done by **optical resonant cavity**.

The second ratio can be maximised by having a higher number of electrons in high energy states than the number of electrons in lower energy state. This condition is quite unnatural which is obtained by optical pumping. The condition $n_2 > n_1$ is called populating inversion.

Light amplification by stimulated emission of radiations.

If there are more electrons in the excited state than in the ground state, favourable condition for stimulated emission is said to exist. This saturation is termed as **population inversion**.

To obtain light amplifications, we must have a mechanism to provide positive feedback at optical frequency, which is done by optical cavity made of perfectly reflecting mirrors on all but one side through which the amplified intense radiation will ultimately escape. A laser can produce a beam of light which is very narrow and very coherent.

2.16 DEVICE TECHNOLOGY

IC Fabrication Processes

Planar technology for IC Fabrication consists of six or seven independent processes: (1) Crystal growth and wafer preparation, (2) Epitaxial growth, (3) Oxidation, (4) Photolithography and chemical etching, (5) Diffusion, (6) Ion implantation and (7) Metallization.



Fig. 2.26

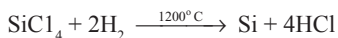
Crystal Growth and Wafer Preparation

A tiny seed crystal of silicon is attached to a rod and lowered into a crucible of molten silicon to which acceptor impurities have been added. As the rod is very slowly pulled out of the melt under carefully controlled conditions, a single *p*-type crystal ingot of the order of 4 inch (10 cm) in diameter and 20 inch (50 cm) long is grown. This technique is referred to as Czochralski or CZ process. The ingot is subsequently sliced into round wafers approximately 0.2 mm thick to form the substrate on which all integrated components will be fabricated. One side of each wafer is lapped and polished to eliminate surface imperfections before proceeding with the next process.

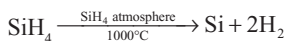
Epitaxial Growth

In IC fabrication, the epitaxial process is used to grow a layer of single crystal silicon as an extension of an existing crystal wafer of the same material. Epitaxial growth is performed in a special furnace called a reactor into which the finished silicon wafers are inserted and heated to 900 to 1000°C. Current production technology uses the hydrogen reduction of the gases silane (SiH_4) or silicon tetrachloride (SiCl_4) as the source of the silicon to be grown. Silane has the advantages of requiring lower temperature and having a faster growth rate than does SiCl_4 .

The chemical reaction for the hydrogen reduction of SiCl_4 is:



And that for silane is



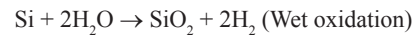
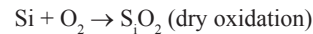
An *n*-type epitaxial layer, typically 5 to 25 μm ($1 \mu\text{m} = 10^{-6} \text{ m} = 10^{-3} \text{ mm}$) thick, is grown into a *p*-type substrate, which has a resistivity of approximately $10 \Omega\cdot\text{cm}$, corresponding to $NA = 1.4 \times 10^{15} \text{ atoms/cm}^3$. The epitaxial process described above indicates that the resistivity of the *n*-type epitaxial layer can be chosen independently of that of the substrate. Values of 0.1 to $0.5 \Omega\cdot\text{cm}$ are chosen for the *n*-type layer.

Oxidation

Fundamental to the overwhelming use of silicon technology is the ability to grow an oxide layer on the silicon surface. The salient characteristics of SiO_2 as a passivating layer are:

1. It is capable of being etched by hydrogen fluoride (HF) to which the underlying silicon is impervious.
2. The impurities used to dope the silicon do not penetrate the silicon dioxide. Thus, when used with the masking techniques, selective doping of specific regions of the chip is accomplished.

Most often, thermal oxidation of silicon is achieved in the presence of water vapour. The chemical reaction is:



The thickness of the oxide layers is generally in the order of 0.02 to 2. μm ; the specific value selected depends on the barrier required to prevent dopant penetration. Process temperature, impurity concentration, and processing time are several factors that influence the thickness of the SiO_2 layer.

Photolithography

The monolithic technique requires the selective removal of the SiO_2 to form openings through which impurities may be diffused. During the photolithographic process, the wafer is coated with uniform film of a photo sensitive emulsion. A large black and white layout of the desired pattern of openings is made and then reduced photographically. This negative, or stencil, of the required dimensions is placed as a mask over the photoresist, or stencil. By exposure of the emulsion to ultraviolet (UV) light through the mask, the photoresist becomes polymerized under the transparent regions of the stencil. The mask is now removed, and the wafer is “developed” by using a chemical (such as trichloroethylene) which dissolves the unexposed (unpolymerized) portions of the photoresist film and leaves the surface pattern. The emulsion which was not removed in development is now fixed, or cured, so that it becomes resistant to the corrosive etches used next.

The smallest features that can be formed by the photolithographic process described in the foregoing paragraphs are limited by a wavelength of light electron beams (X-Rays) have much smaller wavelengths than optical radiation and are capable of defining much smaller areas. Hence, electron beam lithography is now used in the production of masks. A narrow electron beam scans mask conversed with an electron sensitive resist. In this manner, the pattern is written on the mask, with the scanning controlled by a computer. The advantages of this method of mask preparation are higher resolution, the elimination of two photographic reduction steps, and shorter production time in commercial production. The higher cost of the equipment for electron beam lithography is often offset by the advantages that accrue.

Diffusion

Diffusion of impurities into silicon is the basic step in the planar process. The introduction of controlled impurity concentrations is performed in a diffusion furnace at a temperature of about 1000°C over a one to two hours period. The diffusion over usually accommodates twenty wafers in a quartz carrier inside a quartz tube. The temperature must be carefully controlled so that it is uniform over the entire hot zone of the furnace. Impurity sources can be gases, liquids, or solids and are brought into contact with the exposed silicon surface in the furnace. Gaseous impurities used are generally the hydrides of boron, arsenic, and phosphorus. An inert gas (nitrogen) transports the impurity atoms to the surface of the wafers where they diffuse into the silicon.

Ion Implantation

A second method of introducing impurities is ion implantation. In a vacuum, a beam of appropriate ions (boron for p type and phosphorus for n type) are accelerated by energies between 30 and 200 k eV. The depth of penetration of these ions is determined by the accelerating energy and the beam current (the concentration of dopant ions). This process is frequently used where thin layers of doped silicon are required, such as the emitter region of a BJT, the channel in a MOSFET, and the gate region of a JFET. For such narrow regions, ion implantation permits the doping concentrations to be more readily controlled than does diffusion.

The SiO_2 passivation layer forms an effective barrier against implanted ions, so that only the photolithographically defined regions are doped. A second advantage of ion implantation is that

it is performed at low temperatures. Consequently, previously diffused (or implanted) regions have a lesser tendency for lateral spreading.

Metallization

The metallization process is used to form the interconnections of the components on the chip. These are formed by the deposition of a thin layer of aluminum (the conductor most frequently used) over the entire surface of the chip. Deposition is achieved by high-vacuum evaporation inside a bell jar. The aluminum is heated until it vapourizes; the gaseous molecules formed uniformly radiate in all directions and completely cover the wafer surface. A mask is used to define the connection pattern between components and the unwanted aluminum is etched and removed.

2.17 CMOS TECHNOLOGY

Complementary metal oxide semiconductor circuits require that both NMOS and PMOS enhancement transistors can be fabricated on the same chip. The PMOS transistor is fabricated within an n -type well that is implanted or diffused into the p substrate. This n -type region acts as the body B_2 or the substrate of the PMOS transistor, and at least one additional masking and etching process is required to obtain this n region. The second additional processing step needed is the ion implantation of the p -type source and drain regions of the PMOS device. The processes by which the oxide regions, the polysilicon gate areas, and metallization are accomplished are identical to those for the NMOS enhancement transistor.

QUESTION BANK

LEVEL 1

1. If temperature of an extrinsic semiconductor is increased so that the intrinsic carrier concentration is doubled, then
 - (a) The majority carrier density doubles
 - (b) The minority carrier density doubles
 - (c) The minority carrier density becomes 4 time the original value
 - (d) Both majority and minority carrier densities double
2. At room temperature, the current in an intrinsic semiconductor is due to
 - (a) Holes
 - (b) Electrons
 - (c) Ions
 - (d) Holes and electrons
3. For a photoconductor with equal electron and hole mobilities and perfect Ohmic contacts at the ends, an increase in the intensity of optical illumination results in
 - (a) A change in open circuit voltage
 - (b) A change in short-circuit current
 - (c) A reduction of resistance
 - (d) An increase of resistance
4. Gold is often diffused into silicon PN junction devices to
 - (a) Increase the recombination rate
 - (b) Reduce the recombination rate
 - (c) Make silicon a direct gap semiconductor
 - (d) Make silicon semi-metal
5. Consider the following statements:
 Assertion (A): The input impedance of insulated gate MOSFET is very high
 Reason (R): The current in MOSFETs is due to majority carriers.
 Of the statements:
 - (a) Both A and R are true and R is the correct explanation of A
 - (b) Both A and R are true, but R is not correct. explanation of A
 - (c) A is true, but R is false
 - (d) A is false, but R is true
6. If both the emitter-base and the collector-base junction of a bipolar transistor are forward biased, the transistor is in the
 - (a) Active region
 - (b) Saturated region
 - (c) Cut-off region
 - (d) Inverse mode
7. Silicon is not suitable for fabrication of light emitting diodes because it is
 - (a) An indirect band gap semiconductor
 - (b) A direct band gap semiconductor
 - (c) A wide band gap semiconductor
 - (d) A narrow band gap semiconductor
8. Consider the following:
 Compared to silicon, gallium arsenide (GaAs) has
 1. Higher signal speed since electron mobility is higher
 2. Poorer crystal quality since stoichiometric growth, difficult
 3. Easier to grow crystals since the vapour pressure arsenic is high
 4. Higher optoelectronic conversion efficiency
 Of these statements:
 - (a) 1, 2, 3 and 4 correct
 - (b) 1, 2 and 3 are correct
 - (c) 3 and 4 are correct
 - (d) 1, 2, and 4 are correct
9. A good ohmic contact on a *P*-type semiconductor chip is formed by introducing
 - (a) Gold as an impurity below the contact
 - (b) A high concentration of donors below the contact
 - (c) A high concentration of acceptors below the contact
 - (d) A thin insulator layer between the metal and semiconductor
10. Which one of the following bipolar transistors has the highest current gain bandwidth product (fr) for similar geometry?
 - (a) NPN germanium transistor
 - (b) NPN silicon transistor
 - (c) PNP germanium transistor
 - (d) PNP silicon transistor
11. For a junction FET in the pinch-off region, as the drain voltage is increased, the drain current
 - (a) Become zero
 - (b) Abruptly decreases
 - (c) Abruptly increases
 - (d) Remains constant
12. In modern MOSFETs, the material used for the gate is
 - (a) High purity silicon
 - (b) High purity silica
 - (c) Heavily doped polycrystalline silicon
 - (d) Epitaxial grown silicon
13. Consider the following statements:
 In a differential amplifier using a FET pair, the differential output offset voltage is due to
 1. Mismatch between FET parametres
 2. Difference between the value of resistors used in the circuit even though they are marked nominally equal
 3. Variation in the operating voltage of the circuit
 Of these statements:
 - (a) 1, 2 and 3 are correct
 - (b) 2 and 3 are correct
 - (c) 1 and 3 are correct
 - (d) 1 and 2 are correct
14. Measurement of Hall coefficients in a semiconductor provides information on the
 - (a) Sign and mass of charge carriers
 - (b) Mass and concentration of charge carriers
 - (c) Sign of charge carries alone
 - (d) Sign and concentration of charge carriers
15. Excess carriers are generated in a sample of N-type semiconductor by shining light at one end. The current flow in the sample will be made up of
 - (a) Diffusion flow of carriers
 - (b) Drift flow of carriers

- (c) Both diffusion and drift flow of carriers
(d) Neither diffusion nor drift flow of carriers
16. Of the various capacitances associated with a junction transistor, the gain-bandwidth product is affected to a maximum extent by
(a) Base-collector parasitic capacitance
(b) Base-collector space charge layer capacitance
(c) Base-emitter space charge layer capacitance
(d) Base-emitter diffusion capacitance
17. The modulation of effective base width by collector voltage is known as Early Effect, hence reverses collector voltage
(a) Increases both alpha and beta
(b) Decreases both alpha and beta
(c) Increases alpha but decreases beta
(d) Decreases alpha but increases beta
18. The ON voltage and forward break over voltage of an SCR depend on the
(a) Gate current alone
(b) Band gap of the semiconductor alone
(c) Gate current and the semiconductor band gap respectively
(d) Semiconductor alone
19. Which of the following characteristics of a silicon PN junction diode make it suitable for use as an ideal diode?
1. It has very low saturation current
2. It has a high value of forward cut-in voltage
3. It can withstand large reverse voltage
4. When compared with germanium diodes, silicon diodes show a lower degree of temperature dependence under reverse bias conditions.
- Select the correct answer using the codes given below:
Codes:
(a) 1 and 2 (b) 1, 2, 3 and 4
(c) 2, 3 and 4 (d) 1 and 3
20. An incremental model of a solid state device is one which represents the
(a) Ac property of the device at the desired operating point
(b) Dc property of the device at all operating points
(c) Complete ac and dc behaviour of device at all operating points
(d) Ac property of the device at all operating points.
21. Consider the following statements
The threshold voltage of a MOSFET can be lowered by
1. Using a thinner gate oxide
2. Reducing the substrate concentration
3. Increasing the substrate concentration
Of these statements:
(a) 3 alone is correct (b) 1 and 2 are correct
(c) 1 and 3 are correct (d) 2 alone is correct
22. Which one of the following statements regarding the two-transistor model of the p-n-p-n four-layer device is correct?
(a) It explains only the turn ON portion of the device characteristic
(b) It explains only the turn OFF portion of the device characteristic
(c) It explains only the negative region portion of the device characteristic
(d) It explains all the region of the device characteristic.
23. Consider the following steps:
1. Etching 2. Exposure to UV radiation
3. Stripping 4. Developing
After a wafer has been coated with photo resist, the correct sequence of these steps in photolithography is
(a) 2, 4, 3, 1 (b) 2, 4, 1, 3
(c) 4, 2, 1, 3 (d) 3, 2, 3, 1
24. An ideal constant source is connected in series with an ideal constant current source. Considered together, the combination will be
(a) Constant voltage source
(b) Constant current source
(c) Constant voltage and a constant current source or a constant power source
(d) Resistance
25. In a junction transistor, the collector cut off current ' I_{CBO} ' reduces considerably by doping the
(a) Emitter with high level of impurity
(b) Emitter with low level of impurity
(c) Collector with high level of impurity
(d) Collector with low level of impurity
26. A p-n junction diode's dynamic conductance is directly proportional to
(a) The applied voltage (b) The temperature
(c) Its current (d) The thermal voltage
27. In an integrated circuit the SiO_2 layer provides
(a) Electrical connection to external circuit
(b) Physical strength
(c) Isolation
(d) Conducting path
28. Measurement of Hall coefficient enables the determination of
(a) Mobility of charge carriers
(b) Type of the conductivity and concentration of charge carriers
(c) Temperature coefficient and thermal conductivity
(d) Fermi level and forbidden energy gap
29. The output V-I characteristics of an enhancement type MOSFET has
(a) Only a Ohmic region
(b) Only a saturation region
(c) An Ohmic region at low voltage value followed by a saturation region at higher voltages
(d) And Ohmic region at large voltage value preceded by a saturation region at lower voltages
30. Consider the following statements:
In the fabrication of an integrated circuit, the advantages of ion-implantation over diffusion doping are that
1. It is a low temperature process
2. Point imperfections are not produced

3. Shallow doping is possible
 4. Previous steps in fabrication are not affected
- Of these statements:
- (a) 1, 2 and 3 are correct (b) 2, 3 and 4 are correct
 - (c) 1, 3 and 4 are correct (d) 1, 2 and 4 are correct
- 31.** What is the correct sequence of the following step in the fabrication of a monolithic, bipolar junction transistor?
1. Emitter diffusion
 2. Base diffusion
 3. Buried layer formation
 4. Epi-layer formation
- Select the correct answer using the codes given below:
- Codes:**
- (a) 3, 4, 1, 2 (b) 4, 3, 1, 2
 - (c) 3, 4, 2, 1 (d) 4, 3, 2, 1
- 32.** Consider the following statements:
The turn-off time of an SCR can be reduced by
1. Quick withdrawal of the gate voltage
 2. Reducing life-time by doping with gold
 3. Applying a negative pulse to the gate
- Of these statements:
- (a) 1, 2 and 3 are correct (b) 1 and 2 are correct
 - (c) 1 and 3 are correct (d) 2 and are correct
- 33.** Which of the following will serve as a donor impurity in silicon?
- (a) Boron (b) Indium
 - (c) Germanium (d) Antimony
- 34.** The nature of crystal binding in germanium is
- (a) Ionic (b) Metallic
 - (c) Covalent (d) Van der wall type
- 35.** Which of the following will serve as a donor impurity in silicon?
- (a) Boron (b) Indium
 - (c) Germanium (d) Antimony
- 36.** The mean free path for electron drift increases with
- (a) Purity (b) Strain gardening
 - (c) Elastic modulus (d) None of the above
- 37.** Almost all resistors are made in a monolithic integrated circuit
- (a) During the emitter diffusion
 - (b) While growing the epitomical layer
 - (c) During the base diffusion
 - (d) During the collector diffusion
- 38.** Which one of the following pairs of semiconductors and current carriers is correctly matched?
- (a) Intrinsic → No of electrons = No of holes
 - (b) P-type → No of electrons > No of holes
 - (c) N-type → No of electrons < No of holes
 - (d) Bulk → Neither electrons nor holes
- 39.** Which of the following statements is correct?
- (a) Copper has partially filled conduction band
 - (b) Diamond has completely filled conduction band but empty valence band
 - (c) Silicon has a partially filled conduction band and an empty valence band
 - (d) The energy gap between conduction and valence bands in diamond is smaller than in silicon
- 40.** Ultra violet radiation is emitted when electron jumps from an outer stationary orbit to
- (a) First stationary orbit (b) Second stationary orbit
 - (c) Third stationary orbit (d) Fourth stationary orbit
- 41.** N-type semi conductors
- (a) are negatively charged
 - (b) are produced when indium is added as an impurity to Germanium
 - (c) are produced when phosphorus is added as an impurity to silicon
 - (d) none of the above
- 42.** Consider the following statements:
The function of an oxide layer in an IC device is to
1. Mask against diffusion or ion-implant
 2. Insulate the surface electrically
 3. Increase the melting point of silicon
 4. Produce a chemically stable protective layer
- Of these statements:
- (a) 1, 2 and 3 are correct (b) 1,3 and 4 are correct
 - (c) 2, 3 and 4 correct (d) 1, 2 and 4 are correct
- 43.** If large amounts of power are required, a push-pull amplifier is designed for operation as
- (a) class-A (b) class-B
 - (c) class-AB (d) class-C
- 44.** A Darlington pair is used for
- (a) Low distortion (b) High frequency range
 - (c) High power gain (d) High current gain
- 45.** An ideal power supply is
- (a) Zero internal resistance
 - (b) Very large input resistance
 - (c) Very small output resistance
 - (d) Very large output resistance
- 46.** For an n-channel JFET, having drain-source voltage constant if the gate-source voltage is increased (more negative) pinch-off would occur for
- (a) High value of drain current
 - (b) Saturation value of drain current
 - (c) Zero drain current
 - (d) Gate current equal to the drain current
- 47.** When a junction transistor is operated under saturated conditions
- (a) Both the CB and EB junctions are forward biased
 - (b) The CB junction is forward biased but the EB junction is reverse biased
 - (c) The CB junction is reverse biased but the EB junction is forward biased
 - (d) Both the CB and EB junction are reverse biased

48. Consider the following statements associated with bipolar junction transistor and junction gate FET
1. The former has higher impedance than the latter
 2. The former has higher frequency capability than the latter
 3. The latter has lower noise figure than the former
 4. The latter has higher power rating than the former
- Of these statements:
- (a) 1 and 2 are correct
 - (b) 2 and 3 are correct
 - (c) 3 and 4 are correct
 - (d) 2 and 4 are correct
49. Which of the following effects can be caused by a rise in the temperature?
1. Increases in MOSFET current (I_{DS})
 2. Increases in BJT current (I_C)
 3. Decreases in MOSFET current (I_{DS})
 4. Decreases in BJT current (I_C)
- Of these statements:
- (a) 1, 2, 3 are correct
 - (b) 2, 3 are correct
 - (c) 1, 2, 4 are correct
 - (d) 2, 3, 4, are correct
50. The threshold voltage of an n channel MOSFET can be increased by
- (a) Increasing the channel dopant concentration
 - (b) Reducing the channel dopant concentration
 - (c) Reducing the gate oxide thickness
 - (d) Reducing the channel length
51. A zener diode works on the principle of
- (a) Tunneling of charge carrier across the junction
 - (b) Thermionic emission
 - (c) Diffusion of charge carriers across the junction
 - (d) Hopping of charge carriers across the junction
52. A BJT is said to be operating in the saturation region if
- (a) Both the junctions are reverse biased
 - (b) Base-emitter junction is reverse biased and base-collector junction is forward biased
 - (c) Base-emitter junction is forward biased and base-collector junction is reverse-biased
 - (d) Both the junctions are forward biased
53. If a transistor is operating with both of its junctions forward biased, but with the collector base forward bias greater than the emitter-base forward bias, then it is operating in the
- (a) Forward active mode
 - (b) Reverse saturation mode
 - (c) Reverse active mode
 - (d) Forward saturation mode
54. A common emitter BJT amplifier, the maximum usable supply voltage is limited by
- (a) Avalanche breakdown of Base-Emitter junction
 - (b) Collector-Base breakdown voltage with emitter open (V_{CBO})
 - (c) Collector-Emitter breakdown voltage with base open (V_{CEO})
 - (d) Zener breakdown voltage of the Emitter-Base junction
55. For small signal a.c operation, a practical forward biased diode can be modeled as
- (a) A resistance and a capacitance in series
 - (b) An ideal diode and resistance in parallel
 - (c) A resistance and an ideal diode in series
 - (d) A resistance
56. The early effect in a bipolar junction transistor is caused by
- (a) Fast turn-on
 - (b) Fast turn-off
 - (c) Large collector-base reverse bias
 - (d) Large emitter-base forward bias
57. MOSFET can be used as a
- (a) Current controlled capacitor
 - (b) Voltage controlled capacitor
 - (c) Current controlled inductor
 - (d) Voltage controlled inductor
58. The effective channel length of a MOSFET in saturation decreases with an increase in
- (a) gate voltage
 - (b) drain voltage
 - (c) source voltage
 - (d) body voltage
59. n -type silicon is obtained by doping silicon with
- (a) Germanium
 - (b) Aluminum
 - (c) Boron
 - (d) Phosphorus
60. The action of a JFET in its equivalent circuit can be best be represented as a
- (a) Current Controlled Current Source
 - (b) Current Controlled Voltage Source
 - (c) Voltage Controlled Voltage Source
 - (d) Voltage Controlled Current Source
61. The impurity commonly used for realizing the base region of a silicon n - p - n transistor is
- (a) Gallium
 - (b) Indium
 - (c) Boron
 - (d) Phosphorus
62. Under high electric fields, in a semiconductor with increasing electric field
1. The mobility of charge carriers decreases
 2. The mobility of charge carriers increases
 3. The velocity of the charge carriers saturates
 4. The velocity of the charge carriers increases
- Of these statements:
- (a) 1, 2, 3 are correct
 - (b) 1, 3 are correct
 - (c) 1, 2, 4 are correct
 - (d) 2, 3, 4, are correct
63. In a forward biased photo diode with increase in incident light intensity, the diode current
- (a) increases
 - (b) remains constant
 - (c) decreases
 - (d) remaining constant, the voltage drop across the diode increases
64. In a junction diode
1. The depletion capacitance increases with increases in the reverse bias
 2. The depletion capacitance decreases with increases in the reverse bias

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3. The diffusion capacitance increases with the increases in forward bias
4. The diffusion capacitance is much higher than the depletion capacitance when it is forward biased
Of these statements:
(a) 1, 2, 3 are correct (b) 1, 3 are correct
(c) 1, 2, 4 are correct (d) 2, 3, 4 are correct
65. An infra-red LED is usually fabricated from
(a) Ge (b) Si
(c) GaAs (d) GaAs P
66. The built-in potential (Diffusion Potential) in a PN junction
 1. Is equal to the difference in the Fermi level of the two sides, expressed in volts
 2. Increases with the increase in the doping levels of the two sides
 3. Increases with the increase in temperature
 4. Is equal to the average of Fermi levels of the two sides
 Of these statements:
(a) 1, 2, 3 are correct (b) 1, 3 are correct
(c) 1, 2, 4 are correct (d) 2, 3, 4 are correct
67. The drift velocity of electrons, in silicon
 - (a) Is proportional to the electric field for all values of electric field
 - (b) Is independent of the electric field
 - (c) Increases at low values of electric field and decreases at high values of electric field exhibiting negative differential resistance
 - (d) Increases linearly with electric field at low values of electric field and gradually saturates at higher values of electric field
68. The diffusion potential across a P – N junction
 - (a) Decreases with increasing doping concentration
 - (b) Increases with decreasing band gap
 - (c) Does not depend on doping concentrations
 - (d) Increases with increases in doping concentrations
69. The break down voltage of a transistor with its base open is BV_{CEO} and that with emitter open is BV_{CBO} then
(a) $BV_{CEO} = BV_{CBO}$ (b) $BV_{CEO} > BV_{CBO}$
(c) $BV_{CEO} < BV_{CBO}$ (d) BV_{CEO} is not related to BV_{CBO}
70. For a MOS capacitor fabricated on a p type semiconductor, strong inversion occurs when
 - (a) Surface potential is equal to Fermi potential
 - (b) Surface potential is zero
 - (c) Surface potential is negative and equal to Fermi potential in magnitude
 - (d) Surface potential is positive and equal to twice the Fermi potential
71. A long specimen of p-type semiconductor material
 - (a) Is positively charged
 - (b) Is electrically neutral
 - (c) Has an electric field along its length
 - (d) Acts as a dipole
72. The p-type substrate in a conventional P–N junction isolated integrated circuit should be connected to
 - (a) Nowhere, i.e., left floating
 - (b) A dc ground potential
 - (c) The most positive potential available in the circuit
 - (d) The most negative potential available in the circuit
73. The primary reason for the widespread use of Silicon in semiconductor device technology is
 - (a) Abundance of Silicon on the surface of the Earth
 - (b) Large band-gap of Silicon in comparison to Germanium
 - (c) Favourable properties of Silicon-dioxide (SiO_2)
 - (d) Lower melting point
74. An MOS capacitor made using p type substrate is in the accumulation mode. The dominant charge in the channel is due to the presence of
 - (a) holes
 - (b) electrons
 - (c) positively charged ions
 - (d) negatively charged ions
75. The concentration of minority carriers in an extrinsic semiconductor under equilibrium is
 - (a) Directly proportional to the doping concentration
 - (b) Inversely proportional to the doping concentration
 - (c) Directly proportional to the intrinsic concentration
 - (d) Inversely proportional to the intrinsic concentration
76. Under low level injection assumption, the injected minority carrier current for an extrinsic semiconductor is essentially the
 - (a) Diffusion current
 - (b) Drift current
 - (c) Recombination current
 - (d) Induced current
77. In a P–N junction diode under reverse bias, the magnitude of electric field is maximum at
 - (a) The edge of the depletion region of the p-side
 - (b) The edge of the depletion region on the n-side
 - (c) The p–n junction
 - (d) The centre of the depletion region on the n-side
78. n-type silicon is obtained by doping silicon with
 - (a) Germanium (b) Aluminum
 - (c) Boron (d) Phosphorus
79. The action of a JFET in its equivalent circuit can best be represented as a
 - (a) Current Controlled Current Source
 - (b) Current Controlled Voltage Source
 - (c) Voltage Controlled Voltage Source
 - (d) Voltage Controlled Current Source
80. The impurity commonly used for realizing the base region of a silicon n-p-n transistor is
 - (a) Gallium (b) Indium
 - (c) Boron (d) Phosphorus
81. The sensitivity of photodiode depends upon
 - (a) Light intensity and depletion region width
 - (b) Depletion region width and excess carrier life time

- (c) Excess carrier life time and forward bias current
(d) Forward bias current and light intensity
82. The bonding forces in compound semiconductors, such as GaAs, arise from
(a) Ionic bonding
(b) Metallic bonding
(c) Covalent bonding
(d) Combination of ionic and covalent bonding
83. Consider the following statements in connection with the biasing of semiconductor diodes
1. LEDs are used under forward-bias condition
 2. Photodiodes are used under forward bias condition
 3. Zener diodes are used under reverse-bias condition
 4. Variable capacitance diodes are used under reverse bias condition
- Which of these statements are correct?
- (a) 1, 2 and 3 (b) 1, 2 and 4
(c) 2, 3 and 4 (d) 1, 3 and 4
84. Early effect in BJT refers to
(a) Avalanche breakdown (b) Thermal runaway
(c) Base narrowing (d) Zener breakdown
85. The Darlington pair is mainly used for
(a) Impedance matching
(b) Wideband voltage amplification
(c) Power amplification
(d) Reducing distortion
86. In a p-n junction, to make the depletion region extent predominantly into p-region the concentration of impurities in the p-region must be
(a) Much less than the concentration of impurities in n-region
(b) Much higher than the concentration of impurities in n-region
(c) Equal to the concentration of impurities in n-region
(d) Zero
87. What is the reverse recovery time of a diode when switched from forward bias V_F to reverse bias V_R ?
(a) Time taken to remove the stored minority carries
(b) Time taken by the diode minority carries zero value
(c) Time to remove the stored minority carriers plus the time to bridge the diode voltage to reverse bias V_R
(d) Time taken by the diode current to reverse bias V_R
88. From a measurement of the rise time of the output pulse of an amplifier whose input is a small amplitude square wave, one can estimate the following parametre of the amplifier
(a) Gain-bandwidth product
(b) Slew rate
(c) Upper 3-dB frequency
(d) Lower 3-dB frequency
89. The nature of crystal binding in germanium is
(a) Ionic (b) Metallic
(c) Covalent (d) Vander Waal type

90. Resistive films in MIC's are needed to fabricate resistors and attenuators. The feature desirable in resistance films are
(a) Low temperature coefficient of resistance (TCR)
(b) Lower loss
(c) Good adhesion to the substrate
(d) Good etchability and tolerability

LEVEL 2

1. A sample of N -type semiconductor has electron density of $6.25 \times 10^{18}/\text{cm}^3$ at 300 K. If the intrinsic concentrating of carriers in this sample is $2.5 \times 10^{13}/\text{cm}^3$, at this temperature, the hole density works out to be
(a) $10^6/\text{cm}^3$ (b) $10^8/\text{cm}^3$
(c) $10^{10}/\text{cm}^3$ (d) $10^{12}/\text{cm}^3$
2. The current through a PN junction diode with V volts applied to the P region relative to the N region (where, I_0 is the reverse saturation current of the diode, m the ideality factor, k the Boltzmann constant, T the absolute temperature and q the magnitude of charge on an electron) is
(a) $I_0 (e^{-qV/mkT} - 1)$ (b) $I_0 (e^{-qV/mkT})$
(c) $I_0 (1 - e^{qV/mkT})$ (d) $I_0 (e^{-qV/mkT} - 1)$
3. The small signal input impedance of a transistor when the output is shorted for the measuring signal, is (where the symbols have then usual meaning)
(a) $h_{11} = \frac{V_1}{i_1} \Big|_{V_2=0}$ (b) $h_{12} = \frac{V_1}{i_1} \Big|_{I_1=0}$
(c) $h_{21} = \frac{i_2}{i_1} \Big|_{V_2=0}$ (d) $h_{22} = \frac{i_2}{V_2} \Big|_{I_1=0}$
4. The reverse saturation current of a solar cell is 10 and the light generated short-circuit current is I_L for one sun illumination. The open circuit voltage of the solar cell under one sun illumination is (where, k is the Boltzmann constant, T the absolute temperature and q the magnitude of the charge of an electron)
(a) $\frac{KT/n}{q} \left(1 + \frac{I_L}{I_0} \right)$ (b) $\frac{q/n}{KT} \left(1 + \frac{I_L}{I_0} \right)$
(c) $\left(\frac{KT}{n} \right) (I_0 + I_L)$ (d) $\frac{KT}{n} (I_L - I_0)$
5. Typical values of h parametres, at about 1mA collector current, for small signal audio transistors in the CE configuration are
- | h_{ie} | h_{re} | h_{fe} | h_{oe} |
|------------|-----------|----------|----------|
| (a) 100Ω | 10^{-1} | 50 | 1 ms |
| (b) 5 kΩ | 10^{-4} | 200 | 20 ms |
| (c) 5 kΩ | 0 | 20 | 3 ms |
| (d) 100 kΩ | 10^2 | 100 | 10 ms |
6. In a p -type semiconductor, the conductivity due to holes ($= \sigma_p$) is equal to (e = charge of hole, μ_p = hole concentration)
(a) $\frac{p \cdot e}{\mu_o}$ (b) $\frac{\mu_o}{p \cdot e}$
(c) $p \cdot e \cdot \mu_o$ (d) $\frac{1}{p \cdot e \mu_o}$

7. The minority carriers life-time and diffusion constant in a semi conducting material are respectively 100 micro second and 100 cm²/s. The diffusion length of the carriers is
 - (a) 0.1 cm
 - (b) 0.01 cm
 - (c) 0.0141 cm
 - (d) 1 cm
8. The conductivity of an intrinsic semiconductor is (symbols have the usual meanings)
 - (a) Generally less than that of a doped semiconductor
 - (b) Given by $\sigma_i = en_i (\mu_n - \mu_p)$
 - (c) Given by $\sigma_i = en_i (\mu_n + \mu_p)$
 - (d) Given by $\sigma_i = n_i (\mu_n + \mu_p)$
9. For an abrupt junction vector diode, the dependence of device capacitance (C) on applied reverse bias (V) is given by
 - (a) $C \propto V^{-1/3}$
 - (b) $C \propto V^{-1/3}$
 - (c) $C \propto V^{-1/2}$
 - (d) $C \propto V^{-1/2}$
10. For a bipolar junction transistor, if the current amplification factor and cut-off frequency in the CB mode are ∞_{CB} and $f \propto_{CB}$ respectively, then the cut-off frequency in the CE mode is equal to
 - (a) $\frac{f \propto_{CB}}{\infty_{CB}}$
 - (b) $f \propto_{CB} (1 - \infty_{CB})$
 - (c) $\frac{f \propto_{CB}}{1 - \infty_{CB}}$
 - (d) $\infty_{CB} f \propto_{CB}$
11. In a p-n junction, the space charge capacitance is proportional to V^n where, V is the applied bias voltage and 'n' is a constant. The value of 'n' for step, linearly graded and diffused junctions would be respectively
 - (a) $\frac{1}{2}, \frac{1}{3}$ and $\frac{1}{2.5}$
 - (b) $\frac{1}{3}, \frac{1}{2}$ and $\frac{1}{2.5}$
 - (c) $\frac{1}{2}, \frac{1}{2.5}$ and $\frac{1}{3}$
 - (d) $\frac{1}{3}, \frac{1}{2.5}$ and $\frac{1}{2}$
12. In a wafer, a junction depth of x_i is achieved by a constant source diffusion process of 1 hour diffusion time. How long should the diffusion process continue, if a junction depth of $2x_i$ is to be achieved?
 - (a) 2 hours
 - (b) 4 hours
 - (c) 5 hours
 - (d) 7 hours
13. For a photo induced current of I_λ the collector current of phototransistor will be
 - (a) $(h_{fe} + 1) I_\lambda$
 - (b) $\frac{I_2}{h_{fe} + 1}$
 - (c) $h_{fe} \cdot I_2$
 - (d) $\frac{I_2}{h_{fe}}$
14. Given that the band gap of cadmium sulphide is 2.5 eV, the maximum photon wavelength, for electron-hole pair generation will be
 - (a) 5400 μm
 - (b) 540 μm
 - (c) 5400 $\text{\AA}$
 - (d) 540 $\text{\AA}$
15. The threshold voltage of an n-channel enhancement mode MOSFET is 0.5 V. When the device is biased at a gate voltage of 3 V. Pinch-off would occur at a drain voltage of
 - (a) 1.5 V
 - (b) 2.5 V
 - (c) 3.5 V
 - (d) 4.5 V
16. The zero gate bias channel resistance of a junction field effect transistor is 750 ohms and the pinch-off voltage is 3V. For a gate bias of 1.5 V and very low drain voltage, device would behave as a resistance of
 - (a) 320 ohms
 - (b) 816 ohms
 - (c) 1000 ohms
 - (d) 1270 ohms
17. A transistor emitter base voltage V_{EB} of 20 mV has a collector current I_C of 5 mA. For V_{EB} of 30 mV, I_C is 30 m. If V_{EB} is 10 mV, then the I_C will be
 - (a) 55 mA
 - (b) 60 mA
 - (c) 180 mA
 - (d) 270 m
18. A series resonant circuit has an inductive reactance of 1000 Ω , a capacitive reactance of 1000 Ω and a resistance of 0.1 Ω . If resonant frequency is 10 MHz, then the bandwidth of the circuit will be
 - (a) 10 kHz
 - (b) 1 kHz
 - (c) 1 MHz
 - (d) 0.1 kHz
19. In a junction transistor biased for operation at emitter current ' I_E ' and collector current ' I_C ' the trans-conductance ' g_m ' is
 - (a) KT/qI_E
 - (b) qI_E/KT
 - (c) I_C/I_E
 - (d) I_E/I_C
20. A PN junction diode's dynamic conductance is directly proportional to
 - (a) The applied voltage
 - (b) The temperature
 - (c) Its current
 - (d) The thermal voltage
21. The trans-conductance ' g_m ' of a JEET is equal to
 - (a) $-\frac{2I_{DSS}}{V_p}$
 - (b) $\frac{2}{\left| \frac{V_p}{V_p} \right|} \sqrt{I_{DSS} I_{DS}}$
 - (c) $-\frac{2I_{DS}}{V_p}$
 - (d) $\frac{I_{DSS}}{V_p} \left(1 - \frac{V_{GS}}{V_p} \right)$
22. To avoid thermal runaway in the design of an analog circuit, the operating point of the BJT should be such that it satisfies the condition
 - (a) $V_{CE} = \frac{1}{2} V_{CC}$
 - (b) $V_{CE} \leq \frac{1}{2} V_{CC}$
 - (c) $V_{CE} \geq \frac{1}{2} V_{CC}$
 - (d) $V_{CE} \leq 0.78 V_{CC}$
23. If V_r is the reverse voltage across a graded PN junction; then the junction capacitance C_j is proportional to
 - (a) $(V_r)^2$
 - (b) $(V_r)^n$
 - (c) $(V_r)^{-n}$
 - (d) $(V_r)^{3/2}$
24. The Ewers-Moll equation for I_E in CB configuration is given by
 - (a) $I_E = \alpha_n I_c I_{ECO}$
 - (b) $I_E = \alpha_I I_c + I_{CO}$
 - (c) $I_E = \alpha_n I_c + I_{ECO} (e^{qV_{EB}/kT} - 1)$
 - (d) $I_E = \alpha_I I_c + I_{ECO} (e^{qV_{EB}/kT} - 1)$

25. For a BJT, under the saturation condition

- (a) $I_C = \beta I_B$
- (b) $I_C > \beta I_B$
- (c) I_C is independent of all other parameters
- (d) $I_C < \beta I_B$

26. The ratio of the dc component of a full-wave rectified sinusoid to the available power of the rectified sinusoid is

- (a) $\frac{8}{\pi}$
- (b) $4\sqrt{\frac{2}{\pi^2}}$
- (c) $4\sqrt{\frac{2}{\pi}}$
- (d) $\frac{8}{\pi^2}$

27. When n_e and n_h are the electron and hole densities, μ_e and μ_h are the carrier mobilities the Hall coefficient is positive when

- (a) $n_h \mu_h > n_e \mu_e$
- (b) $n_h \mu_h^2 > n_e \mu_e^2$
- (c) $n_h \mu_h < n_e \mu_e$
- (d) $n_h \mu_h^2 < n_e \mu_e^2$

28. Quantum effects have to be taken into account in determining the properties of materials if

- (a) $E_F = 3/2 KT$
- (b) $E_F < 3/2 KT$
- (c) $E_F > 3/2 KT$
- (d) $E_F \gg 3/2 KT$

29. For the junction transistor, which of the following relations is true?

- (a) $\alpha = \frac{\beta}{1-\beta}$
- (b) $\alpha = \beta(1+\beta)$
- (c) $\beta = \frac{\alpha}{1-\alpha}$
- (d) $\beta = \frac{\alpha}{1+\alpha}$

30. For a UJT if

R_1 = resistance from emitter to the base 1

R_2 = resistance from emitter to the base 2

And $R_{BB} = R_1 + R_2$ then the intrinsic stand off ratio (η) is

- (a) R_1/R_2
- (b) R_1/R_{BB}
- (c) R_2/R_1
- (d) R_2/R_{BB}

31. In the Fermi-Dirac statistics, the probability of electron occupation of an energy level equal to the Fermi level is

- (a) 0
- (b) 0.25
- (c) 0.5
- (d) 1.0

32. If P_r is the rate at which carriers are produced by light in a photo-diode, τ is the average life time for the newly created carriers, T_i is the average transit time for carriers to reach the Ohmic contacts of the diode and ' e ' is the electronic charge, then the steady-state photo-current will be given by

- (a) $i = \frac{2e P_r \tau}{T_i}$
- (b) $i = \frac{e \cdot P_r \cdot \tau}{2T_i}$
- (c) $i = \frac{e P_r \tau}{T_i}$
- (d) $i = \frac{e \cdot P_r \cdot \tau}{3T_i}$

33. In an ideal junction transistor, the impurity concentration in the emitter (E), base (B) and collector (C) are such that

- (a) $E > C > B$
- (b) $B > C > E$
- (c) $C > E > B$
- (d) $C = E = B$

34. The collector to emitter cut-off current (I_{CEO}) of a transistor is related to collector to base cut-off current (I_{CBO}) as (α is the CB current gain of the transistor)

- (a) $I_{CEO} = I_{CBO}$
- (b) $I_{CEO} = \alpha I_{CBO}$
- (c) $I_{CEO} = \frac{I_{CBO}}{1-\alpha}$
- (d) $I_{ECO} = \frac{I_{CBO}}{1-\alpha}$

35. The drain-source output V-I characteristics of an n-channel depletion FET has

- (a) $I_{DS} = 0$ at $V_{GS} = 0$
- (b) I_{DS} = positive maximum at $V_{GS} = 0$
- (c) I_{DS} = negative maximum at $V_{GS} = 0$
- (d) I_{DS} independent of V_{GS}

36. The "Pinch off" voltage of a JFET is 5.0 volts. Its "Cut off" voltage is

- (a) $(5)^{1/2}$ V
- (b) 2.5 V
- (c) 5.0
- (d) $(5.0)^{3/2}$ V

37. An n-channel JFET has a pinch off voltage of $V_p = -5$ V, $V_{DS}(\text{max}) = 20$ V, and $g_m = 2$ mA/V. The minimum 'ON' resistance is achieved in the JFET for

- (a) $V_{GS} = -7$ V and $V_{DS} = 0$ V
- (b) $V_{GS} = 0$ V and $V_{DS} = 0$ V
- (c) $V_{GS} = 0$ V and $V_{DS} = 20$ V
- (d) $V_{GS} = -7$ V and $V_{DS} = 20$ V

38. A silicon n-MOSFET has a threshold voltage of 1 V and oxide thickness of 400 Å. [$\epsilon_r(\text{SiO}_2) = 3.9$, $\epsilon_o = 8.854 \times 10^{-14}$ F/cm, $q = 1.6 \times 10^{-19}$ C]. The region under the gate is ion implanted for threshold voltage tailoring. The dope and type of the implant (assumed to be a sheet charge at the interface) required to shift the threshold voltage to -1 V are

- (a) $1.08 \times 10^{12}/\text{cm}^2$, p-type
- (b) $1.08 \times 10^{12}/\text{cm}^2$, n-type
- (c) $5.4 \times 10^{11}/\text{cm}^2$, p-type
- (d) $5.4 \times 10^{11}/\text{cm}^2$, n-type

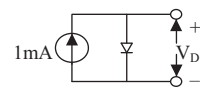
39. Two identical FETs, each characterized by the parameters g_m and r_d are connected in parallel. The composite FET is then characterized by the parameters

- (a) $g_m/2$ and $2r_d$
- (b) $g_m/2$ and $r_d/2$
- (c) $2g_m$ and $r_d/2$
- (d) $2g_m$ and $2r_d$

40. An n-channel JFET has $I_{DSS} = 2$ mA and $V_p = -4$ V. Its trans-conductance g_m (in milliohm) for an applied gate-to-source voltage V_{GS} of -2 V is

- (a) 0.25
- (b) 0.5
- (c) 0.75
- (d) 1.0

41. In figure, a silicon diode is carrying a constant current of 1 mA. When the temperature of the diode is 20° C, V_D is found to be 700 mV. If the temperature rises to 40° C, V_D becomes approximately equal to



- (a) 740 mV
- (b) 660 mV
- (c) 680 mV
- (d) 700 mV

42. The electron concentration in a sample of uniformly doped n-type silicon at 300 K varies linearly from $10^{17}/\text{cm}^3$ at $x = 0$

to $6 \times 10^{16}/\text{cm}^3$ at $x = 2 \mu\text{m}$. Assume a situation that electrons are supplied to keep this concentration gradient constant with time. If electronic charge is 1.6×10^{-19} coulomb and the diffusion constant $D_n = 35 \text{ cm}^2/\text{s}$, the current density in the silicon, if no electric field is present, is

- (a) zero (b) -1120 A/cm^2
(c) $+1120 \text{ A/cm}^2$ (d) -1120 A/cm

43. At 300 K, for a diode current of 1 mA, a certain germanium diode requires a forward bias of 0.1435 V, whereas a certain silicon diode requires a forward bias of 0.718 V. Under the conditions stated above, the closest approximation of the ratio of reverse saturation current in germanium diode to that in silicon diode is

- (a) 1 (b) 5
(c) 4×10^3 (d) 8×10^3

44. When the gate-to-source voltage (V_{GS}) of a MOSFET with threshold voltage of 400 mV, working in saturation is 900 mV, the drain current is observed to be 1 mA. Neglecting the channel width modulation effect and assuming that the MOSFET is operating at saturation, the drain current for an applied V_{GS} of 1400 mV is

- (a) 0.5 mA (b) 2.0 mA
(c) 3.5 mA (d) 4.0 mA

45. If for a silicon n-p-n transistor, the base-to-emitter (V_{BE}) is 0.7 V and the collector-to-base voltage (V_{CB}) is 0.2 V, then the transistor is operating in the

- (a) Normal active mode (b) Saturation mode
(c) Inverse active mode (d) Cutoff mode

46. The drain of an n-channel MOSFET is shorted to the $V_{GS} = V_{DS}$. The threshold voltage (V_T) of MOSFET is 1 V. If the drain current (I_D) is 1 mA for $V_{GS} = 2\text{V}$, then for $V_{GS} = 3\text{V}$, I_D is

- (a) 2 mA (b) 3 mA
(c) 9 mA (d) 4 mA

47. In a uniformly doped abrupt p-n junction, the doping level of the n-side is four (4) times the doping level of the p-side: The ratio of the depletion layer width is

- (a) 0.25 (b) 0.5
(c) 1.0 (d) 2.0

48. A silicon sample is uniformly doped with 10^{16} phosphorus atom/ cm^3 and 2×10^{16} boron atoms/ cm^3 . If all the dopants are fully ionized, the material is

- (a) n-type with carrier concentration of $10^{16}/\text{cm}^3$
(b) p-type with carrier concentration of $10^{16}/\text{cm}^3$
(c) p-type with carrier concentration of $2 \times 10^{16}/\text{cm}^3$
(d) n-type with carrier concentration of $2 \times 10^{16}/\text{cm}^3$

49. A semiconductor is irradiated with light such that carriers are uniformly generated throughout its volume. The semiconductor is n-type with $N_D = 10^{19}$ per cm^3 . If the excess electron concentration in the steady state is $\Delta n = 10^{15}$ per cm^3 and if $\tau_p = 10 \mu\text{sec}$ [minority carrier life time] the generation rate due to irradiation

- (a) is 10^{20} e-h pair/ cm^3/s
(b) is 10^{24} e-h pairs/ cm^3/s

- (c) is 10^{10} e-h pairs/ cm^3/s

- (d) cannot be determined as the given data is insufficient

50. A P-N junction in series with a 100 ohms resistor, is forward biased so that a current of 100 mA flows. If the voltage across this combination is instantaneously reversed to 10 V at $t = 0$, the reverse current that flows through the diode at $t = 0$ is approximately given by

- (a) 0 mA (b) 100mA
(c) 200 mA (d) 50mA

51. A material is described by the following electrical parameters as a frequency of 10 GHz, $\sigma = 10^6 \text{ mho/m}$, $\mu = \mu_0$ and $\sigma/\sigma_0 = 10$. The material at this frequency considered to be

$$\sigma_0 = \frac{1}{36\pi} \times 10^{-9} \text{ F/m}$$

- (a) A good conductor
(b) A good dielectric
(c) Neither a good conductor, nor a good dielectric
(d) A good magnetic material

52. A small concentration of minority is injected into a homogeneous semiconductor crystal at one point. An electric field of 10 V-cm is applied across the crystal and this moves the minority carriers a distance of 1 cm is 20 μsec . The mobility (in $\text{cm}^2/\text{volt.sec}$) will be

- (a) 1,000 (b) 2,000
(c) 5000 (d) 500000

53. The probability that an electron in a metal occupies the Fermi-level, at any temperature ($> 0 \text{ K}$) is

- (a) 0 (b) 1
(c) 0.5 (d) 0.1

54. In a P type silicon sample, the hole concentration is $2.25 \times 10^{15}/\text{cm}^3$. If the intrinsic carrier concentration is $1.5 \times 10^{10}/\text{cm}^3$, the electron concentration is

- (a) zero (b) $10^{10}/\text{cm}^3$
(c) $10^5/\text{cm}^3$ (d) $1.5 \times 10^{25}/\text{cm}^3$

55. The depletion capacitance, C_j of an abrupt P-N junction with constant doping on either side varies with reverse bias, V_R , as

- (a) $C_j \propto V_R$ (b) $C_j \propto V_R^{-1}$
(c) $C_j \propto V_R^{-1/2}$ (d) $C_j \propto V_R^{-1/3}$

56. A n-channel silicon ($E_g = 1.1 \text{ eV}$) MOSFET was fabricated using n^+ poly-silicon gate and the threshold voltage was found to be 1 V. Now, if the gate is changed to P^+ poly-silicon, other things remaining the same, the new threshold voltage should be

- (a) -0.1 V (b) 0 V
(c) 1.0 V (d) 2.1 V

57. The intrinsic carrier density at 300 K is $1.5 \times 10^{10}/\text{cm}^3$, in silicon. For n-type silicon doped to $2.25 \times 10^{15} \text{ atoms}/\text{cm}^3$, the equilibrium electron and hole densities are

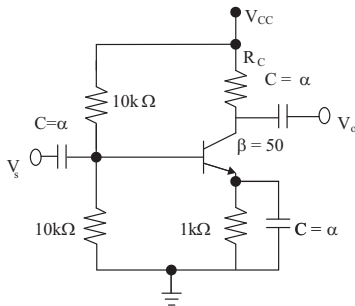
- (a) $n = 1.5 \times 10^{15}/\text{cm}^3$, $p = 1.5 \times 10^{10}/\text{cm}^3$
(b) $n = 1.5 \times 10^{10}/\text{cm}^3$, $p = 2.25 \times 10^{15}/\text{cm}^3$
(c) $n = 2.25 \times 10^{15}/\text{cm}^3$, $p = 1.0 \times 10^5/\text{cm}^3$
(d) $n = 1.5 \times 10^{10}/\text{cm}^3$, $p = 1.5 \times 10^{10}/\text{cm}^3$

58. The band-gap of silicon at 300 K is
 (a) 1.36 eV (b) 1.10 eV
 (c) 0.80 eV (d) 0.67 eV
59. Intrinsic carrier concentration of silicon sample at 300° K is $1.5 \times 10^{16}/\text{m}^3$. If after doping, the number of majority carriers is $5 \times 10^{20}/\text{m}^3$, the minority carrier density is
 (a) $4.50 \times 10^{11}/\text{m}^3$ (b) $3.33 \times 10^4/\text{m}^3$
 (c) $5.00 \times 10^{20}/\text{m}^3$ (d) $3.00 \times 10^{-5}/\text{m}^3$
60. An n-type silicon bar, 0.1 cm long and $100 \mu\text{m}^2$ in cross sectional area, has a majority carrier concentration of $5 \times 10^{20}/\text{m}^3$ and the carrier mobility is $0.13\text{m}^2/\text{Vs}$ at 300 K. If the charge of an electron is 1.6×10^{-19} coulomb, then the resistance of the bar is
 (a) 10^6 ohm (b) 10^4 ohm
 (c) 10^{-1} ohm (d) 10^{-4} ohm
61. A particular green LED emits light of wavelength 5490 Å. The energy band-gap of the semiconductor material used there is (Planck's constant = 6.626×10^{-34} J-s)
 (a) 2.26 eV (b) 1.98 eV
 (c) 1.17 eV (d) 0.74 eV
62. In an abrupt p-n junction, the doping concentrations on the p-side and n-side are $N_A = 9 \times 10^{16}/\text{cm}^3$ and $N_D = 1 \times 10^{16}/\text{cm}^3$ respectively. The p-n junction is reverse biased and the total depletion width is 3 μm . The depletion width on the p-side is
 (a) 2.7 μm (b) 0.3 μm
 (c) 2.25 μm (d) 0.75 μm
63. The resistivity of a uniform doped n-type silicon sample is $0.5 \Omega\text{-cm}$. If the electron mobility (μ_n) is $1250 \text{ cm}^2/\text{V-sec}$ and the charge of an electron is 1.6×10^{-19} Coulomb, the donor impurity concentration (N_D) in the sample is
 (a) $2 \times 10^{16}/\text{cm}^3$ (b) $1 \times 10^{16}/\text{cm}^3$
 (c) $2.5 \times 10^{15}/\text{cm}^3$ (d) $5 \times 10^{15}/\text{cm}^3$
64. Consider an abrupt p-junction. Let V_{bi} be the built-in potential of this junction and V_R be the applied reverse bias. If the junction capacitance (C_j) is 1 pF for $V_{bi} + V_R = 1 \text{ V}$, then for $V_{bi} + V_R = 4 \text{ V}$, C_j will be
 (a) 4 pF (b) 2 pF
 (c) 0.25 pF (d) 0.5 pF
65. The longest wavelength that can be absorbed by silicon, which has the band-gap of 1.12 eV, is 1.1 μm . If the longest wavelength that can be absorbed by another material is 0.87 μm , then the band-gap of this material is
 (a) 1.416 eV (b) 0.886 eV
 (c) 0.854 eV (d) 0.706 eV
66. The neutral base width of a bipolar transistor, biased in the active region, is 0.5 μm . The maximum electron concentration and the diffusion constant in the base are $10^{14}/\text{cm}^3$ and $D_n = 25 \text{ cm}^2/\text{sec}$ respectively. Assuming negligible recombination in the base, the collector current density is (the electron charge is 1.6×10^{-19} coulomb)
 (a) 800 A/cm² (b) 8 A/cm²
 (c) 200 A/cm² (d) 2 A/cm²
67. The band gap of Silicon at room temperature is
 (a) 1.3 eV (b) 0.7 eV
 (c) 1.1 eV (d) 1.4 eV
68. A Silicon PN junction at a temperature of 20°C has a reverse saturation current of 10 pico-Amperes (pA). The reverse saturation current at 40°C for the same bias is approximately
 (a) 30 pA (b) 40 pA
 (c) 50 pA (d) 60 pA
69. A Silicon sample A is doped with 10^{18} atoms/cm² of Boron. Another sample B of identical dimensions is doped with 10^{18} atoms/cm³ of Phosphorus. The ratio of electron to hole mobility is 3. The ratio of conductivity of the sample A to B is
 (a) 3 (b) [1/3]
 (c) [2/3] (d) [3/2]
70. A Silicon PN junction diode under reverse bias has depletion region of width 10 μm . The relative permittivity of Silicon, $\epsilon_r = 11.7$ and the permittivity of free space $\epsilon_0 = 8.85 \times 10^{-12}$ F/m. The depletion capacitance of the diode per square metre is
 (a) 100 μF (b) 10 μF
 (c) 1 μF (d) 20 μF
71. The values of voltage (V_D) across a tunnel-diode corresponding to peak and valley currents are V_p and V_v respectively. The range of tunnel diode voltage V_D for which the slope of its $I - V_D$ characteristics is negative would be
 (a) $V_D < 0$ (b) $0 \leq V_D < V_p$
 (c) $V_p \leq V_D < V_v$ (d) $V_D \geq V_v$
72. A heavily doped n-type semiconductor has the following data
 Hole-electron mobility ratio: 0.4
 Doping concentration: 4.2×10^8 atoms/m³
 Intrinsic concentration: 1.5×10^4 atoms/m³
 The ratio of conductance of the n-type semiconductor to that of the intrinsic semiconductor of same material and at the same temperature is given by
 (a) 0.00005 (b) 2,000
 (c) 10,000 (d) 20,000
73. The electron and hole concentrations in an intrinsic semiconductor are n_i per cm³ at 300 K. Now, if acceptor impurities are introduced with a concentration of N_A per cm³ (where, $N_A \gg n_i$), the electron concentration per cm³ at 300 K will be
 (a) n_i (b) $n_i + N_A$
 (c) $N_A - n_i$ (d) n_i^2/N_A
74. A P⁺n junction has a built-in potential of 0.8 V. The depletion layer width at a reverse bias of 1.2 V is 2 μm . For a reverse bias of 7.2 V, the depletion layer width will be
 (a) 4 μm (b) 4.9 μm
 (c) 8 μm (d) 12 μm
75. The DC current gain (β) of a BJT is 50. Assuming that the emitter injection efficiency is 0.995, the base transport factor is
 (a) 0.980 (b) 0.985
 (c) 0.990 (d) 0.995

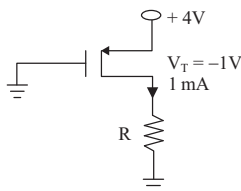
76. For an n-channel enhancement type MOSFET, if the source is connected at a higher potential than that of the bulk (i.e., $V_{SB} > 0$), the threshold voltage V_T of the MOSFET will
 (a) remain unchanged (b) decrease
 (c) change polarity (d) increase
77. An n-type silicon bar 0.1 cm long and $100 \mu\text{m}^2$ in cross sectional area has a majority carrier concentration of $5 \times 10^{20}/\text{m}^3$ and the carrier mobility is $0.13\text{m}^2/\text{Vs}$ at 300 K. If the charge of an electron is 1.5×10^{-19} coulomb, then the resistance of the bar is
 (a) 10^6 ohm (b) 10^4 ohm
 (c) 10^{-1} ohm (d) 10^{-4} ohm
78. A particular green LED emits light of wavelength 5490 Å. The energy band gap of the semiconductor material used there is (Planck's constant = 6.626×10^{-34} J-s)
 (a) 2.26 eV (b) 1.98 eV
 (c) 1.17 eV (d) 0.74 eV
79. If P is passivation, Q is n-well implant, R is metallization and S is source/drain diffusion, then the order in which they are carried out in a standard n-well CMOS fabrication process, is
 (a) P-Q-R-S (b) Q-S-R-P
 (c) R-P-S-Q (d) S-R-Q-P

LEVEL 3

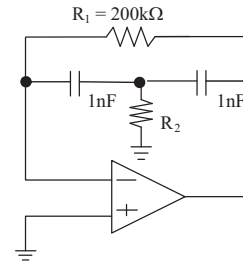
1. The transconductance g_m of the transistor shown in the figure is 10 mS. The value of the input resistance R_{IN} is



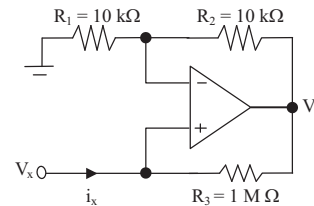
- (a) 10.0 kΩ (b) 8.3 kΩ
 (c) 5.0 kΩ (d) 2.5 kΩ
2. The value of R for which the PMOS transistor in the figure will be biased in linear region is



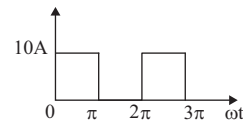
- (a) 220 Ω (b) 470 Ω
 (c) 680 Ω (d) 1200 Ω
3. In the active filter, the circuit shown in the figure, if $Q = 1$, a pair of poles will be realized with ω_0 equal to



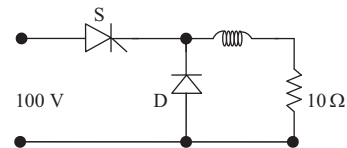
- (a) 10000 rad/s (b) 100 rad/s
 (c) 10 rad/s (d) 1 rad/s
4. The input resistance R_{IN} ($= v_x/i_x$) of the circuit in the figure is



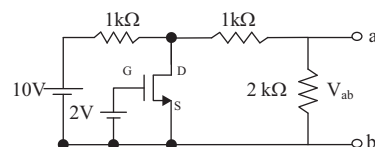
- (a) +100 kΩ (b) -100 kΩ
 (c) +1 MΩ (d) -1 MΩ
5. A MOSFET rated for 15 A, carries a periodic current as shown in the figure. The ON state resistance of the MOSFET is 0.15 Ω. The average ON state loss in the MOSFET is



- (a) 33.8 W (b) 15.0 W
 (c) 7.5 W (d) 3.8 W
6. Figure shows a chopper operating from a 100 V dc input. The duty ratio of the main switch S is 0.8. The load is sufficiently inductive so that the load current is ripple free. The average current through the diode D under steady state is

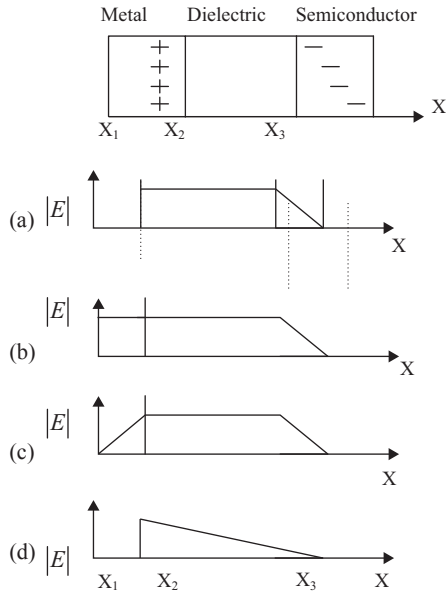


- (a) 1.6 A (b) 6.4 A
 (c) 8.0 A (d) 10.0 A
7. Assume that the N-channel MOSFET shown in the figure is ideal, and that its threshold voltage is +1.0V. The voltage V_{ab} between nodes a and b is

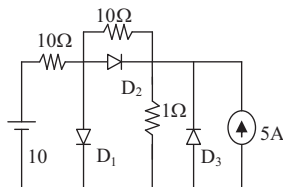


- (a) 5 V (b) 2 V
(c) 1 V (d) 0 V

8. The charge distribution in the metal-dielectric-semiconductor specimen is shown in the figure. The negative charge density decreases linearly in the semiconductor as shown. The electric field distribution is as shown in

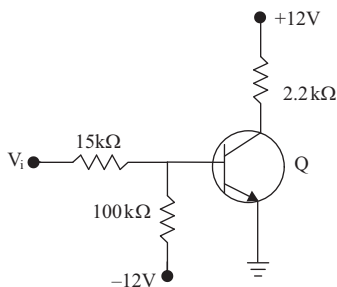


9. What are the states of the three ideal diodes of the circuit shown in the figure?



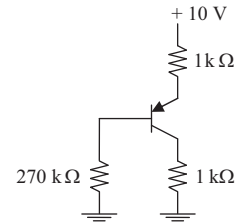
- (a) D_1 ON, D_2 OFF, D_3 OFF
(b) D_1 OFF, D_2 ON, D_3 OFF
(c) D_1 ON, D_2 OFF, D_3 ON
(d) D_1 OFF, D_2 ON, D_3 ON

10. Consider the circuit shown in the figure. If the β of the transistor is 30 and I_{CBO} is $20 \mu A$ and the input voltage is +5 V, the transistor would be operating in



- (a) Saturation region (b) Active region
(c) Breakdown region (d) Cut-off region

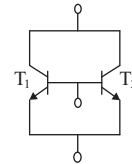
11. The common emitter forward current gain of the transistor shown is $\beta_F = 100$



The transistor is operating in

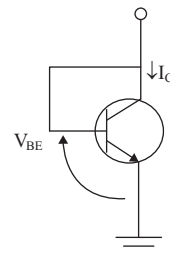
- (a) Saturation region
(b) Cut-off region
(c) Reverse active region
(d) Forward active region

12. Discrete transistors T_1 and T_2 having maximum collector current rating of 0.75 amps are connected in parallel as shown in the figure. This combination is treated as a single transistor to carry a total current of 1 ampere, when biased with self bias circuit. When the circuit is switched on, T_1 draws 0.55 amps and T_2 draws 0.45 amps. If the supply is kept on continuously, ultimately it is very likely that



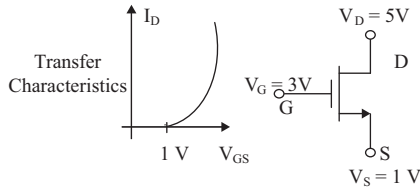
- (a) both T_1 and T_2 get damaged
(b) both T_1 and T_2 will be safe
(c) T_1 Will get damaged and T_2 will be safe
(d) T_2 will get damaged and T_1 will be safe

13. For an npn transistor connected as shown in the figure, $V_{BE} = 0.7$ volts. Given that reverse saturation current of the junction at room temperature $300^\circ K$ is $10^{-13} A$, the emitter current is



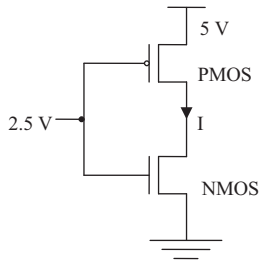
- (a) 30 mA (b) 39 mA
(c) 49 mA (d) 20 mA

14. For an n-channel MOSFET and its transfer curve shown in the figure, the threshold voltage is



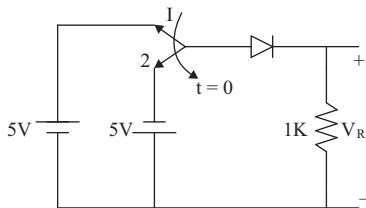
- (a) 1 V and the device is in active region
 (b) -1 V and the device is in saturation region
 (c) 1 V and the device is in saturation region
 (d) -1 V and the device is in active region

15. In the CMOS inverter circuit shown, if the transconductance parameters of the NMOS and PMOS transistors are $k_n = k_p = \mu_n C_{ox} \frac{W_n}{L_n} = \mu_p C_{ox} \frac{W_p}{L_p} = 40 \mu A/V^2$ and their threshold voltages are $V_{Thn} = |V_{Thp}| = 1V$, the current I is



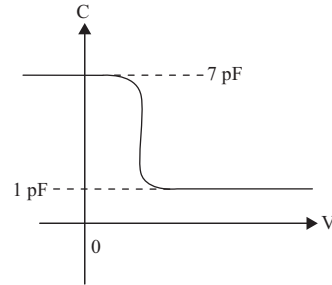
- (a) 0 A
 (b) 25 μA
 (c) 45 μA
 (d) 90 μA

16. In the circuit shown below, the switch was connected to position 1 at $t < 0$, and at $t = 0$ it is changed to position 2. Assume that the diode has zero voltage drop and a storage time t_s . For $0 < t \leq t_s$, V_R is given by (all in Volts)



- (a) $V_R = -5$
 (b) $V_R = +5$
 (c) $0 \leq V_R < 5$
 (d) $-5 < V_R < 0$

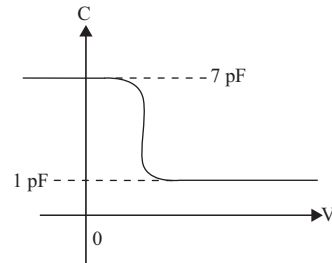
17. The figure shows the high-frequency capacitance-voltage (C-V) characteristic of a Metal/SiO₂/silicon (MOS) capacitor having an area of $1 \times 10^{-4} \text{ cm}^2$. Assume that the permittivities ($\epsilon_0 \epsilon_r$) of silicon and SiO₂ are $1 \times 10^{-12} \text{ F/cm}$ and $3.5 \times 10^{-13} \text{ F/cm}$ respectively.



The gate oxide thickness in the MOS capacitor is

- (a) 50 nm
 (b) 143 nm
 (c) 350 nm
 (d) 1 μm

18. The figure shows the high-frequency capacitance-voltage (C-V) characteristic of a Metal/SiO₂/silicon (MOS) capacitor having an area of $1 \times 10^{-4} \text{ cm}^2$. Assume that the permittivities ($\epsilon_0 \epsilon_r$) of silicon and SiO₂ are $1 \times 10^{-12} \text{ F/cm}$ and $3.5 \times 10^{-13} \text{ F/cm}$ respectively.



The maximum depletion layer width in silicon is

- (a) 0.143 μm
 (b) 0.857 μm
 (c) 1 μm
 (d) 1.143 μm

ANSWER KEYS

LEVEL 1

1. (d)	2. (d)	3. (c)	4. (b)	5. (b)	6. (b)	7. (a)	8. (c)	9. (b)	10. (a)
11. (d)	12. (c)	13. (d)	14. (d)	15. (a)	16. (d)	17. (a)	18. (c)	19. (b)	20. (a)
21. (c)	22. (d)	23. (b)	24. (b)	25. (a)	26. (c)	27. (c)	28. (b)	29. (c)	30. (c)
31. (d)	32. (d)	33. (c)	34. (c)	35. (d)	36. (a)	37. (c)	38. (a)	39. (a)	40. (a)
41. (c)	42. (d)	43. (b)	44. (d)	45. (a)	46. (b)	47. (a)	48. (b)	49. (b)	50. (a)
51. (a)	52. (d)	53. (c)	54. (b)	55. (d)	56. (c)	57. (b)	58. (b)	59. (d)	60. (d)

61. (c)	62. (b)	63. (a)	64. (d)	65. (c)	66. (a)	67. (d)	68. (d)	69. (c)	70. (d)
71. (b)	72. (d)	73. (b)	74. (a)	75. (b)	76. (a)	77. (d)	78. (d)	79. (d)	80. (c)
81. (a)	82. (c)	83. (d)	84. (c)	85. (a)	86. (a)	87. (c)	88. (c)	89. (c)	90. (a)

LEVEL 2

1. (b)	2. (d)	3. (a)	4. (a)	5. (b)	6. (c)	7. (a)	8. (c)	9. (d)	10. (c)
11. (a)	12. (b)	13. (a)	14. (c)	15. (b)	16. (c)	17. (a)	18. (a)	19. (b)	20. (c)
21. (b)	22. (b)	23. (b)	24. (d)	25. (d)	26. (d)	27. (b)	28. (d)	29. (a)	30. (c)
31. (c)	32. (a)	33. (a)	34. (c)	35. (b)	36. (c)	37. (c)	38. (a)	39. (c)	40. (b)
41. (a)	42. (c)	43. (c)	44. (d)	45. (a)	46. (d)	47. (a)	48. (b)	49. (a)	50. (b)
51. (a)	52. (c)	53. (b)	54. (c)	55. (c)	56. (c)	57. (c)	58. (b)	59. (a)	60. (a)
61. (a)	62. (b)	63. (b)	64. (d)	65. (a)	66. (b)	67. (c)	68. (b)	69. (b)	70. (b)
71. (c)	72. (d)	73. (d)	74. (a)	75. (b)	76. (a)	77. (a)	78. (a)	79. (b)	

LEVEL 3

1. (d)	2. (d)	3. (a)	4. (d)	5. (c)	6. (d)	7. (d)	8. (a)	9. (a)	10. (b)
11. (a)	12. (c)	13. (d)	14. (c)	15. (d)	16. (a)	17. (a)	18. (c)		

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CHAPTER

SIGNALS AND

SYSTEMS

3.1 INTRODUCTION TO SIGNALS AND SYSTEMS

Signal may be described in wide variety of physical phenomena. It may be represented in many ways, i.e., variation of some form.

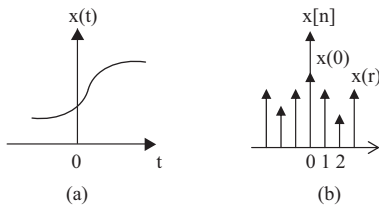


Fig. 3.1 (a) Continuous signal uses symbol t to denote the continuous-time independent variable (b) Discrete time signal uses n to denote the discrete time independent variable

$x[n]$ = having a sequence

$x[n] = a_1 \sin t$ = having one element

Sampling of data gives discrete signal which is used to indicate Aircraft position, velocity, heading.

Time Scaling

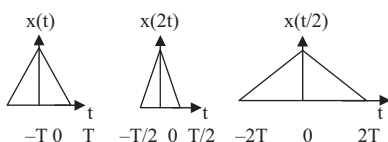


Fig. 3.2

$x(2t)$ played twice the speed and $x(t/2)$ played at half-speed.

Periodic Signals

A periodic signal has the property that it is unchanged by a time shift of T .

$$x(t) = x(t + T)$$

$$\text{and } x[n] = x[n + N]$$

We can say that $x(t)$ is periodic with time period T .

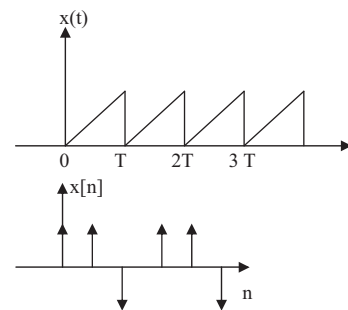


Fig. 3.3 Time period $N_0 = 3$

Even Signals

A signal $x(t)$ or $x[n]$ is even if it is identical to its time-reversed counter part i.e., with its reflection about the origin.

$$x(-t) = x(t); \quad x[-n] = x[n].$$

Odd Signal

$$x(-t) = -x(t); \quad x[-n] = -x[n]$$

odd signal must be 0 at $t = 0$ or $n = 0$

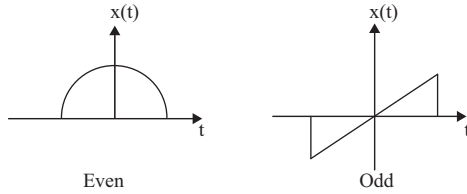


Fig. 3.4

Exponential Signal

$$x(t) = C e^{at}$$

where, C and a are complex number.

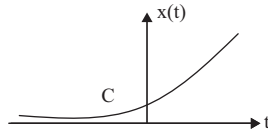


Fig. 3.5

$$x(t) = C e^{at}$$

where, $a > 0$ i.e., +ve

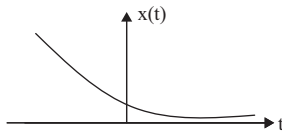


Fig. 3.6

$$x(t) = C e^{at}$$

where, $a < 0$ i.e., -ve

$$\delta[n] = u[n] - u[n-1]$$

There is a close relationship between the discrete time unit impulse and unit step. In particular, the discrete-time impulse is the first difference of the discrete time step.

$$u[n] = \sum_m^n \delta(m) = \sum_{k=0}^n \delta(n-k)$$

The discrete-time step is the running sum of the unit sample.

The unit impulse sequence can be used to sample the value of signal $n = 0$

$$x[n] \delta[n] = x[0] \delta[n]$$

$$x[n] \delta[n - n_o] = x[n_o] \delta[n - n_o]$$

Where, $x[0]$ and $x[n_o]$ represent the amplitude of impulse function at $n = 0$ and $n = n_o$.

The Continuous Signal

Unit step function $u(t)$

$$u(t) = \begin{cases} 0 & ; t < 0 \\ 1 & ; t > 0 \end{cases}$$

Discrete Function

Unit impulse function: The is the same function as delta function in analog.

$$\delta(t) = \begin{cases} 1 & ; \text{for } t = 0 \\ 0 & ; \text{for } t \neq 0 \end{cases}$$

$$\delta[n] = \begin{cases} 1 & ; \text{for } n = 0 \\ 0 & ; \text{for } n \neq 0 \end{cases}$$

Signal Energy and Power

$v(t)$ and $i(t)$ are continuous signals across R .

Instantaneous Power

$$p(t) = v(t) \cdot i(t) = \left(\frac{1}{R} \right) v^2(t)$$

$$\text{The total energy} = \int_{t_1}^{t_2} p(t) dt = \int_{t_1}^{t_2} \left(\frac{1}{R} \right) v^2(t) dt$$

$$\text{Average power} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} p(t) dt$$

For continuous signal $x(t)$

$$\text{Total energy} = \int_{t_1}^{t_2} |x(t)|^2 dt$$

For discrete signal $x[n]$

$$\text{Total energy} = \sum_{n=n_1}^{n_2} |X[n]|^2$$

Total energy of signal for $-\infty < t < +\infty$ or $-\infty < n < +\infty$

$$\text{Continuous Time } E_{\infty} = \lim_{T \rightarrow \infty} \int_{-T}^T |x(t)|^2 dt = \int_{-\infty}^{\infty} |x(t)|^2 dt$$

$$\text{Discrete Time } E_{\infty} = \lim_{T \rightarrow \infty} \sum_{n=-N}^{+N} |x[n]|^2 = \sum_{n=-\infty}^{+\infty} |x[n]|^2$$

$$\text{Time Average Power } P_{\infty} = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^T |x(t)|^2 dt$$

$$P_{\infty} = \lim_{N \rightarrow \infty} \frac{1}{2N+1} \sum_{n=-N}^N |x[n]|^2$$

3.2 SYSTEM

Physical system in the broadest sense is an inter connection of components, devices, or sub-systems.

A system can be viewed as a process in which input signals are transformed by the system or cause. The system respond in some way, resulting in other signals as output examples are, signal processor or communication equipment.

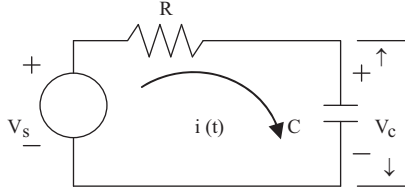


Fig. 3.7

$$i(t) = \frac{V_s(t) - V_c(t)}{R} \quad (1)$$

$$i(t) = \frac{C d V_c(t)}{dt} \quad (2)$$

From equations (1) and (2)

$$\begin{aligned} \frac{dV_c(t)}{dt} + \frac{V_c(t)}{RC} \\ = \frac{1}{RC} V_s(t) \end{aligned} \quad (3)$$

System Properties

(a) System without Memory/Static

A system is said to be memory less if its output for each value of the independent variable at a given time is dependent only on the input at the same time.

Example: $y[n] = \{2x[n] - x^2[n]\}^2$

(b) System with Memory/Dynamic

Presence of mechanism which retain information at time other than current time i.e., capacitor and inductor.

Example: (1) accumulator or summer

$$y[n] = \sum_{k=-\infty}^n n(k) = \sum_{k=-\infty}^{n-1} x(k) + x[n]$$

$$\begin{aligned} (2) \text{ Delay circuit } y[n] &= x[n-1] \\ &= y[n-1] + x[n] \end{aligned}$$

Invariability and Inverse System

A systems is said to lie invertible if distinct input leads to distinct output. If a system is invertible, then an inverse system exists, that when cascaded with the original system, yields an output $w[n]$ equal to the input $x[n]$ to the first system.

Non-invertible System is

$$y[n] = 0 \text{ and } y(t) = x^2(t)$$

1. The system that produces zero output sequence for input.
2. In which we cannot determine the sign of the input from knowledge of output.

Use: Encoder must be invertible in communication system.

Causality

A system is casual if the output at any time depends on value of the input at the present time and in the past. Such system is referred as **non-anticipative** as the system does not anticipate future values of the input.

The RC series circuit is casual as the capacitor voltage responds only to the present and past values of source voltage.

Stability

A stable system is one in which small inputs lead to responds that do not diverge.

For the stable system, if the input to a stable system is bounded, then the output must also be bounded.

The stability of physical system generally results from the presence of mechanism that dissipate energy

$\Rightarrow$ bounded or $\Rightarrow$ stable.

Time Invariance

A system is time invariant if the behaviour and characteristics of the system are fixed over time.

For example, the RC series circuit is time invariant if the resistance and capacitance values are constant.

A system is time invariant if a time shift in the input signal results in the identical shift in the output signal.

If $x(t)$ input then $y(t)$ output

If $x(t - t_0)$ - input then $y(t - t_0)$ output.

Discrete Time Unit Impulse Response

The property of time invariance tells us that the response of the time-invariant system to the time shifted unit impulse are simply time shifted version of one another.

For any discrete LTI system output is given by

$$y[n] = n[n] * h[n]$$

$$\text{where, } x[n] = \sum_{k=-\infty}^{\infty} n(k) \delta[n-k]$$

3.3 CONVOLUTION

Convolution is a mathematical operation and is useful for describing the input output relationship in a linear time variant system. It is an important analytical tool for the communication engineers.

3.4 ■ Signals and Systems

The convolution $f(t)$ of two time functions $f_1(t)$ and $f_2(t)$ is defined by the following integral.

$$f(t) = \int_{\tau=-\infty}^{\infty} f_1(\tau) f_2(t-\tau) d\tau = f_1(t) * f_2(t)$$

Example on Convolution

Discrete Convolution

Convolution is important in digital signal processing because convolving two sequence in the time domain is equivalent to multiplying the sequence in the frequency domain. Convolution finds its application in processing signals especially analyzing the output of a system. Consider the signals $x_1[n]$ and $x_2[n]$. The convolution of these two signals is given by

$$x_3[n] = x_1[n] * x_2[n] = \sum_{k=-\infty}^{\infty} x_1(k) x_2(n-k)$$

Note: Linear convolution results in an aperiodic sequence with a length of $(2N - 1)$.

3.4 DEFINITIONS AND PROPERTIES OF LAPLACE TRANSFORM

The Laplace transformation is a powerful method for solving linear differential equations usually encountered in electrical circuits.

The Laplace transformation reduces the problem of solving differential equations to an algebraic problem.

Another advantage is that it takes care of initial conditions without the necessity of first determining the general solution and then obtaining from it a particular solution.

While performing Laplace transform, we perform two steps:

1. Multiply function $f(t)$ by $e^{-st} = f(t) \cdot e^{-st}$
2. Integrate from limit 0 to ∞

The direct Laplace transformation of a function $f(t)$ is defined as:

$$F(s) = LT f(t) = \int_0^{\infty} f(t) e^{-st} dt$$

where, s = Complex frequency
 $= \sigma + j\omega$

where, σ = Real

ω = Imaginary

For Fourier Transform, $\sigma \rightarrow 0$

$LT f(t) = F(s)$; $LT^{-1} F(s) = f(t)$

$f(t) \leftrightarrow F(s)$

$f(t)$ and $F(s)$ are Laplace Transform pair

Inverse Laplace Transform, i.e.,

$$LT^{-1}[F(s)] = f(t) = \frac{1}{2\pi j} \int_{\sigma-j\infty}^{\sigma+j\infty} F(s) e^{st} ds$$

Condition for Laplace Transform to exists

$$\int_0^{\infty} |f(t) e^{-st}| dt < \infty$$

$$\Rightarrow \int_0^{\infty} |f(t) e^{-(\sigma+j\omega)t}| dt < \infty$$

$$\text{Now, } |e^{-(\sigma+j\omega)t}| = |e^{-\sigma t}| |e^{-j\omega t}| = e^{-\sigma t} |\cos \omega t - j \sin \omega t|$$

$$= e^{-\sigma t} (\cos^2 \omega t + \sin^2 \omega t)^{1/2} = e^{-\sigma t}$$

$$\text{Then, } \int_0^{\infty} |f(t)| e^{-\sigma t} dt \text{ must be finite}$$

Examples of Laplace transform.

1. $f(t) = \delta(t) \leftarrow$ delta function i.e., Unit Impulse function.
 $LT [\delta(t)] = 1$
2. $f(t) = u(t) \leftarrow$ unit step function
 $= 0; \quad t < 0$
 $= 1; \quad t > 0$

$$F(s) = \int_0^{\infty} f(t) e^{-st} dt = \frac{1}{s}$$

3. Unit doublet function $f(t) = \frac{d}{dt} \delta(t)$

$$LT \left(\frac{d}{dt} \delta(t) \right) = s$$

4. Unit triplet function parabola

$$\frac{d^2}{dt^2} \delta(t) \rightarrow s^2$$

5. $f(t) = t^n$

$$\therefore F(s) = \frac{n!}{s^{n+1}} \leftrightarrow t^n$$

6. Unit parabola $\frac{t^2}{2} \rightarrow \frac{1}{s^3}$

7. $f(t) = e^{-at} \leftarrow$ exponential function

$$LT[e^{-at}] = \int_0^{\infty} e^{-(s+a)t} dt = \frac{1}{s+a}$$

8. $f(t) = \sin a t \leftarrow$ sinusoidal function

$$LT[\sin a t] = \frac{a}{s^2 + a^2}$$

9. $f(t) = \cos a t \leftarrow$ cosinusoidal function

$$LT[\cos a t] = \frac{s}{s^2 + a^2}$$

10. $f(t) = \sinh a t \leftarrow$ hyperbolic function

$$= \frac{1}{2} [e^{at} - e^{-at}]$$

$$LT[\sinh a t] = \frac{a}{s^2 - a^2}$$

$$11. f(t) = \cos h a t$$

$$LT[\cos h a t] = \frac{s}{s^2 - a^2}$$

$$12. f(t) = e^{-bt} \cdot \sin a t$$

$$e^{-bt} \sin a t \leftrightarrow \frac{a}{(s+b)^2 + a^2}$$

$$13. f(t) = e^{-bt} \cdot \cos a t$$

$$e^{-bt} \cos a t \leftrightarrow \frac{s+b}{(s+b)^2 + a^2}$$

$$14. f(t) = e^{-bt} \sin h a t$$

$$e^{-bt} \sin h a t \leftrightarrow \frac{a}{(s+b)^2 - a^2}$$

$$15. f(t) = e^{-bt} \cdot \cos h a t \leftrightarrow \frac{s+b}{(s+b)^2 - a^2}$$

$$16. f(t) = t e^{-at}$$

$$t e^{-at} \leftrightarrow \frac{1}{(s+a)^2}$$

Take the denominator term of Laplace transform of (e^{-at}) and put this value, where, s term is there in Laplace transform of t term.

Time Shifting/Displacement Theorem

$$f(t) = f(t - T)$$

$$LT f(t - T) = F(s) e^{-sT}$$

Laplace Transform of Derivative

$$LT\left(\frac{d f(t)}{dt}\right) = \int_0^\infty \frac{d}{dt} f(t) e^{-st} dt = sF(s) - f(0)$$

where, $f(0)$ represent initial value.

Laplace of Second Derivative

$$LT\left(\frac{d^2 f(t)}{dt^2}\right) = LT\left(\frac{d}{dt} \cdot \frac{d f(t)}{dt}\right)$$

$$= s^2 F(s) - s f(0) - f'(0)$$

Laplace Transform of an Integral of Time

$$LT\left(\int_0^t f(t) dt\right) = \int_0^\infty \left(\int_0^t f(t) dt\right) e^{-st} dt$$

Assume $\int f(t) dt \Big|_{t=0} = f^{-1}(0)$ i.e., Initial value

$$\therefore LT \int f(t) dt = \frac{F(s)}{s} + \frac{f^{-1}(0)}{s}$$

$$LT \int f^n(t) = \frac{F(s)}{s^n} + \frac{f^{-1}(0)}{s^n} + \frac{f^{-2}(0)}{s^{n-1}} + \dots$$

Initial Value Theorem

$$f(0^+) = \lim_{t \rightarrow 0} f(t) = \lim_{s \rightarrow \infty} s F(s)$$

Final Value Theorem

$$f(\infty) = \lim_{t \rightarrow \infty} f(t) = \lim_{s \rightarrow 0} [s F(s)]$$

These theorems enable us to evaluate $f(0^+)$ and $f(\infty)$ by examining the limiting value of $F(s)$. The theorems are very useful particularly in the servo mechanism theory.

Complex Translation

If $f(t) \leftrightarrow F(s)$, then multiplication of $f(t)$ by the exponential time function e^{-at} becomes a translation in the s domain and vice versa, i.e., $LT [e^{-at} f(t)] = F(s + a)$.

Laplace Transform of a Periodic Function

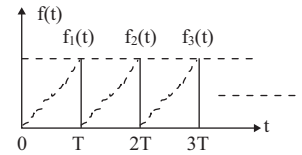


Fig. 3.8

$$F(s) = \frac{F_1(s)}{1 - e^{-sT}}$$

Here $F_1(s)$ is the Laplace transform of a function $f_1(t)$ which is being repeated periodically with time period of T .

3.5 CONTINUOUS-TIME FOURIER SERIES

Fourier Series

Any periodic signal can be represented by some infinite number of sinusoids of harmonic frequencies where the composite set of function consisting of a set $\cos n \omega_o t$ and $\sin n \omega_o t$ for $(n = 0, 1, \dots, 2)$ form a complete **orthogonal set**.

Mutually Orthogonal Function

Two real time functions are said to be “mutually orthogonal” over an interval between t_1 and t_2 if the integral of their product over this interval is zero; i.e., $f(t)$ is orthogonal to $h(t)$, if

$$\int_{t_1}^{t_2} f(t) h(t) dt = 0$$

Therefore, a set of time function $\{g_1(t), g_2(t), \dots\}$ forms an orthogonal set over the interval between t_1 and t_2 if

$$\int_{t_1}^{t_2} g_j(t) g_k(t) dt = 0, \quad (j \neq k)$$

Orthogonality in Complex Function

If $f_1(t)$ and $f_2(t)$ are complex functions of the real variable t , then the two functions are orthogonal over the interval between t_1 and t_2 , if

$$\int_{t_1}^{t_2} f_1(t) f_2^*(t) dt = \int_{t_1}^{t_2} f_1^*(t) f_2(t) dt = 0$$

where, $f_1^*(t)$ and $f_2^*(t)$ are complex conjugates of $f_1(t)$ and $f_2(t)$, respectively. The complex functions $e^{jn\omega_o t}$ ($n = 0, \pm 1, \pm 2, \dots$) form a set of orthogonal functions.

Fourier Series of a Periodic Function $f(t)$

A periodic signal is defined by the relation

$$f(t) = f(t \pm T)$$

where, T = Time period and

$$\omega_o = 2\pi/T$$

A periodic signal $f(t)$ of time period T can be represented by presenting the sum of infinite number of sinusoids of harmonic frequencies $\omega_o, 2\omega_o, 3\omega_o, \dots$ called the Fourier series.

1. $f(t)$ must satisfy the **Dirichlet's condition** i.e.,

- $f(t)$ has only a finite number of maxima and minima in any one period.
- $f(t)$ is discontinuous and has a finite number of discontinuities in any one period.
- $f(t)$ discontinuities are bonded, i.e., it has a finite average values over the period T .

Waveform Symmetry

A. If $f(t)$ is an even function, i.e.,

$f(t) = f(-t)$. For example, $\cos t, t^2, t \sin t$.

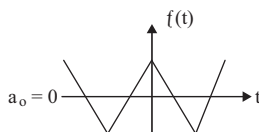
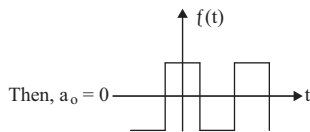


Fig. 3.9

$$a_n = \frac{4}{T} \int_0^{T/2} f(t) \cos(n\omega_o t) dt$$

- $b_n = 0$. The graph of an even function will be symmetrical with respect to the y -axis and only cosine terms are present (dc term optional).
- The sum or product of two or more even functions is an even function.

B. If $f(t)$ is an Odd Function

$-f(t) = f(-t)$; Then,

$$a_o = 0; a_n = 0$$

$$b_n = \frac{4}{T} \int_0^{T/2} f(t) \sin(n\omega_o t) dt$$

- The graph of an odd function is symmetrical about the origin.
- The sum of two or more odd functions is an odd function and product of two odd functions is an even function.
- Only sin terms are present.

C. If $f(t)$ is having Half Wave Symmetry

$-f(t \pm T/2) = f(t)$: Then $a_o = 0$

$$a_n = \frac{4}{T} \int_0^{T/2} f(t) \cos(n\omega_o t) dt$$

$$b_n = \frac{4}{T} \int_0^{T/2} f(t) \sin(n\omega_o t) dt$$

- Only odd harmonic terms are present.
- If $f(t \pm T/2) = f(t)$, then only even harmonic are present.

D. If $f(t)$ is having Quarter Wave Symmetry, i.e.,

(a) Half wave and odd symmetry

$$\begin{array}{ll} a_o = 0 & \text{all } n \\ a_n = 0 & \text{all } n \end{array}$$

$$b_n = \frac{8}{T} \int_0^{T/4} f(t) \sin(n\omega_o t) dt \quad n \text{ odd}$$

$$b_n = 0 \quad n \text{ even}$$

(b) Half wave and even symmetry

$$\begin{array}{ll} a_o = \text{Find out.} & \\ a_n = 0 & n \text{ even} \end{array}$$

$$a_n = \frac{8}{T} \int_0^{T/4} f(t) \cos(n\omega_o t) dt \quad n \text{ odd}$$

$$b_n = 0 \quad \text{all } n$$

Exponential Fourier series:

$$f(t) = \sum_{n=-\infty}^{\infty} F_n e^{jn\omega_o t}$$

$$\text{where, } F_n = \frac{1}{T} \int_0^T f(t) e^{-jn\omega_o t} dt$$

$$F_n = |F_n| e^{-j\theta_n} \quad \theta_n = \tan^{-1} \frac{I_m[F_n]}{R_e[F_n]}$$

$|F_n|$ gives magnitude (discrete) spectrum, i.e., always even function of n , θ_n gives phase (discrete) spectrum, i.e., always an odd function of n .

The mean square value of a periodic function $f(t)$ with period T is defined by

$$P = \frac{1}{T} \int_0^T f(t)^2 dt = \frac{C_o^2}{4} + \sum \frac{C_n^2}{2}$$

$$f(t) = \frac{C_o}{2} + \sum_{n=1}^{\infty} C_n \cos(n\omega_o t + \phi_n)$$

$$P = \frac{C_o^2}{4} + \frac{C_1^2}{2} + \frac{C_2^2}{2} + \dots$$

The power of periodic signal $f(t)$ is dc power plus the ac power of all the components of $f(t)$.

3.6 DISCRETE TIME FOURIER SERIES

Fourier series is a linear combination of harmonically related complex exponential functions. Fourier series is used to represent both continuous-time and discrete-time complex exponentials. A discrete-time signal or sequence is periodic with period N_o , if

$$X[n] = x[n + N_o]$$

The fundamental period is the smallest positive integer N_o for which $\omega_o = [2\pi/N_o]$ is the fundamental frequency. For example, the complex exponential $e^{j\omega_o n}$ is periodic with period N_o . A set of all discrete-time complex exponential signal which are periodic with period N_o are given by.

$$F_k[n] = e^{j\omega_o n} \quad ; \text{ for } k = 0, \pm 1, \pm 2, \dots$$

$$\text{Where, } \omega_o = [2\pi/N_o]$$

All these signals have fundamental frequencies that are multiples of $[2\pi/N_o]$ and thus these are harmonically related.

There are only N_o distinct signals in the set of equation. Thus, discrete-time complex exponentials which differ in frequency by a multiple of 2π are identical.

$$x[n] = \sum_k A_k F_k[n] = \sum_k A_k e^{jk\omega_o n}$$

For example, k can be chosen in any of the combinations such as

$$k = 0, 1, \dots, N_o - 1, \text{ or}$$

$$k = 1, 2, \dots, N_o, \text{ or}$$

$$k = 2, 3, \dots, N_o + 1, \text{ or}$$

$$x[n] = \sum_{k=-\infty}^{\infty} A_k e^{jk\omega_o n}$$

Where,

$$A_k = \frac{1}{N_o} \sum_{n=-\infty}^{\infty} x[n] e^{jk\omega_o n}$$

$$\text{Where, } \omega_o = [2\pi/N_o]$$

As in continuous-time periodic signals, the discrete-time Fourier series coefficients A_k are often called the spectral coefficient of signal $x[n]$. These Fourier series coefficients A_k specify as decomposition of signal $x[n]$ into a sum of no harmonically related complex exponential functions.

3.7 CONTINUOUS-TIME FOURIER TRANSFORM

If the signal occurs once in some finite time interval and is never repeated, then it is analysed by Fourier integral. This is analysed by letting the T_o become infinite in the Fourier series. The line spectrum then becomes a continuous spectrum.

$$f(t) = a_o + \sum_{n=1}^{\infty} (a_n \cos n\omega_o t + b_n \sin n\omega_o t)$$

$$f(t) = \sum_{-\infty}^{\infty} F_n e^{jn\omega_o t} \quad \left[\omega_o = \frac{2\pi}{T} \right]$$

$$\text{where, } F_n = \frac{1}{T} \int_0^T f(t) e^{-jn\omega_o t} dt$$

$|F_n|$ is plotted against $n\omega$. The graph is obtained which will have the general appearance of the figure shown below:

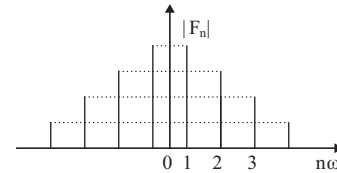


Fig. 3.10 This figure is called the frequency Spectrum of given waveform $f(t)$

The amplitude value has significant value only at the distant value of $n\omega$. Every line created at $n\omega$ for integral n represents the magnitude of the harmonic component whose frequency is n times the fundamental frequency.

Since the spectrum consists of discrete line is called **discrete spectrum**.

If the time period T increases to infinity for single pulse then ω decreases as $\omega = 2\pi/T$. The line in the discrete frequency spectrum gets closer as $T \rightarrow \infty$, i.e., $\omega = 2\pi f = 2\pi/T$, ($T \rightarrow \infty$) $= 0$, i.e., $\omega \rightarrow 0$ and the lines come so closer that the discrete spectrum becomes continuous spectrum.

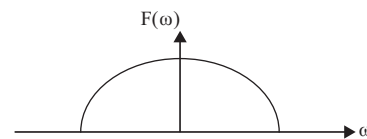


Fig. 3.11

$$F(\omega) = \lim_{T \rightarrow \infty} F_n = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T f(t) e^{-j\omega t} dt$$

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t} dt$$

Conversion of signal from time domain into frequency domain.

It is a useful tool in the study of power spectral, noise and auto correlation function and advance problem.

Let, $f(t)$ is any signal.

$F(\omega)$ = FT of $f(t)$;

$f(t)$ and $F(\omega)$ are fourier transform pair.

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t} dt$$

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) e^{j\omega t} d\omega = \int_{-\infty}^{\infty} F(\omega) e^{j\omega t} df$$

$F(\omega)$ = complex frequency spectrum

$$= |F(\omega)| e^{-j\theta(\omega)}$$

$|F(\omega)|$ = magnitude spectrum (always even function of ω)

$\theta(\omega)$ = phase spectrum (always an odd function of ω)

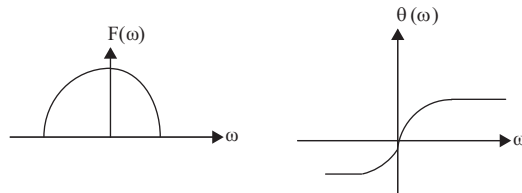


Fig. 3.12

Condition for $F(\omega)$ to Exist

$$\int_{-\infty}^{\infty} |f(t)| dt < \infty, \text{ i.e., area under } f(t) \text{ curve must be finite.}$$

Symmetry Property

Fourier transform of a gate function is sampling function and Fourier transform of sampling function is a gate function. The symmetry property holds for all even function. If $f(t)$ is not even, then symmetry is not proper.

Linearity Property

$$\begin{aligned} \text{If, } f_1(t) &\leftrightarrow F_1(\omega); \\ f_2(t) &\leftrightarrow F_2(\omega) \end{aligned}$$

then, $a_1 f_1(t) + a_2 f_2(t) \leftrightarrow a_1 F_1(\omega) + a_2 F_2(\omega)$ where, a_1 and a_2 are constants.

Scaling Property

$$FT[f(at)] = \frac{1}{|a|} F(\omega/a)$$

$$f(at^2) \rightarrow \frac{1}{\sqrt{|a|}} F(\omega^2/a^2)$$

Frequency shifting property

$$f(t) \leftrightarrow F(\omega)$$

$$\text{Then, } FT[f(t)] e^{-j\omega_o t} = ?$$

$$FT[f(t) e^{j\omega_o t}] = \int_{-\infty}^{\infty} \{f(t) e^{-j\omega_o t}\} e^{-j\omega t} dt$$

$$= \int_{-\infty}^{\infty} f(t) e^{-j(\omega - \omega_o)t} dt = F(\omega - \omega_o)$$

$$FT[f(t) \cos \omega_o t] = \frac{1}{2} [F(\omega - \omega_o) + F(\omega + \omega_o)]$$

..... Modulation theorem

Time Shifting Property

$$\text{If, } f(t) \leftrightarrow F(\omega)$$

$$\text{Then, } FT[f(t - t_o)] = ?$$

$$= F(\omega) e^{-j\omega t_o}$$

Time Differential

$$\text{If } f(t) \leftrightarrow F(\omega)$$

$$\frac{d^n f}{dt^n} \leftrightarrow (j\omega)^n F(\omega)$$

Time Integration

$$f(t) \leftrightarrow F(\omega)$$

Frequency Differentiation

$$f(t) \leftrightarrow F(\omega)$$

(a) Unit step function

$$f(t) = 1; t \geq 0$$

$$= 0; t < 0$$

(b) Impulse or delta function

$$f(t) = \delta(t) = \infty; t = 0$$

$$= 0; t \neq 0$$

Then, it is called delta function.

(c) Properties of delta function

- $\int_{-\infty}^{\infty} \delta(t) dt = 1$
- $\int_{-\infty}^{\infty} g(t) \delta(t) dt = g(t) \Big|_{t=0} = g(0)$
- $\int_{-\infty}^{\infty} g(t) \cdot \delta(t-T) dt = g(t) \Big|_{t=T} = g(T)$

Fourier Transform of a Periodic Function

If, $f(t)$ is periodic with time period T , $\omega_o = 2\pi/T$ $f(t)$ can be expressed in the form of exponential fourier series.

$$f(t) = \sum_{n=-\infty}^{\infty} F_n e^{jn\omega_o t}$$

where, $F_n = \frac{1}{T} \int_{-T/2}^{T/2} f(t) e^{-jn\omega_o t} dt$

$$F[f(t)] = 2\pi \sum_{n=-\infty}^{\infty} F_n \delta(\omega - n\omega_o)$$

Fourier Transform of Sinusoidal Function

$$FT[e^{j\omega_o t}] = 2\pi \delta(\omega - \omega_o)$$

Since the cosine and sin functions may be expressed in the term of the exponential factor $e^{j\omega_o t}$.

$$\cos \omega_o t = \frac{[e^{j\omega_o t} + e^{-j\omega_o t}]}{2}$$

$$\sin \omega_o t = \frac{[e^{j\omega_o t} - e^{-j\omega_o t}]}{2j}$$

Example: Find the fourier transform of delta function

$$f(t) = \delta(t) \dots \text{direct delta function.}$$

Solution:

$$F(\omega) = \int_{-\infty}^{\infty} \delta(t) e^{-j\omega t} dt = e^{-j\omega t} \Big|_{t=0} = e^0 = 1$$

$[F(\omega) = 1]$; No phase spectrum as $F(\omega)$ is real.

Example: Find the fourier transform of below function

$$f(t) = A e^{-a|t|}; \text{ for all } t$$

It is double side exponential signal.

Solution:

$$F(\omega) = \frac{2a \cdot A}{a^2 + \omega^2}$$

$F(\omega)$ is real function

$$\theta(\omega) = 0$$

$$\omega = 0; F(\omega) = 2A/a$$

$$\omega = \infty; F(\omega) = 0$$

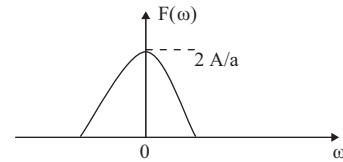


Fig. 3.13 Magnitude spectrum

Important Points to Note

1. Fourier series $\Rightarrow$ Fourier transform
(Integral) (Reasons)
 $\downarrow \downarrow$
Periodic function Non-periodic function

Time domain	Frequency domain
Continuous and periodic	Discrete and a periodic
Discrete and periodic	Discrete and periodic
Continuous and a periodic	Continuous and a periodic
Discrete and a periodic	Continuous and periodic

2. (a) Even symmetry, odd half wave, contain all term. Odd term may be sin or cosin.
(b) Quarter wave symmetry must be even or odd function.
3. The Fourier transform is able to realize the spectrum of given function physically, but the Laplace transform is not able to draw physically spectrum of signal.

Laplace's transform can be applied, when the function become not integrable (not convergent). So that it can be multiplied by $e^{-\sigma t}$. In this transform, ROC must be defined for every transform.

Summary of Properties of the Fourier Transform Property

1. Linearity

$$ag_1(t) + bg_2(t) \leftrightarrow a_1 G_1(f) + b G_2(f)$$

where, a and b are constants.

2. Time scaling

$g(at) \leftrightarrow (1/|a|) G(f/a)$; where a is constant $a > 0$. Compression in time domain $\Leftrightarrow$ Expansion in frequency domain.

$$g(at^2) \rightarrow \frac{1}{\sqrt{|a|}} G(f^2/a^2)$$

3. Duality

$$\text{If } g(t) \leftrightarrow G(f) \text{ then } G(t) \leftrightarrow g(-f)$$

4. Time shifting

$$g(t - t_o) \leftrightarrow G(f) e^{-j2\pi f t_o}$$

5. Frequency shifting

$$e^{j2\pi f_0 t} g(t) \Leftrightarrow G(f-f_0)$$

6. Area under $g(t)$

$$= \int_{-\infty}^{\infty} g(t) dt = G(0)$$

7. Area under $G(f)$

$$g(0) = \int_{-\infty}^{\infty} G(f) df$$

8. Differentiation in time domain

$$\left(\frac{d}{dt}\right) g(t) \Leftrightarrow (j2\pi f) \cdot G(f)$$

9. Integration in the time domain

$$= \int_{-\infty}^{\infty} g(\tau) d\tau \Leftrightarrow \frac{1}{j2\pi f} = G(f) + \frac{G(0)}{2} \delta(f)$$

10. Conjugate function

$$\text{If } g(t) \Leftrightarrow G(f) \text{ then } g^*(t) \Leftrightarrow G^*(-f)$$

11. Multiplication in the time domain $\Leftrightarrow$

Convolution in frequency domain

$$= g_1(t) g_2(t) \Leftrightarrow \int_{-\infty}^{\infty} G_1(\lambda) G_2(f-\lambda) d\lambda$$

12. Convolution in the time domain $\Leftrightarrow$ Multiplication in frequency domain

$$= \int_{-\infty}^{\infty} g_1(\tau) g_2(t-\tau) d\tau \Leftrightarrow G_1(f) \cdot G_2(f)$$

Fourier Transform Pair	
Time function	Fourier transform
$\text{rect}(t/T)$	$T \text{sinc}(fT)$
$\text{sinc}(2\omega t)$	$(1/2\omega) \text{rect}(f/2\omega)$
$e^{-at} u(t); a > 0$	$\frac{1}{a + j2\pi f}$
$e^{-a t }; a > 0$	$\frac{2a}{a^2 + (2\pi f)^2}$
$e^{-\pi t^2}$	$e^{-\pi f^2}$
$\begin{cases} 1 - [t/T] & ; t < T \\ 0, & t \geq T \end{cases}$	$T \text{sinc}^2(fT)$
1	$\delta(f)$
$\delta(t)$	1
$\delta(t-t)$	$e^{-j2\pi f t_0}$
$a^{j2\pi f_c t}$	$\delta(f-f_c)$
$\cos(2\pi f_c t)$	$(1/2) [\delta(f+f_c) + \delta(f-f_c)]$
$\sin(j2\pi f_c t)$	$(1/2j) [\delta(f-f_c) - \delta(f+f_c)]$

$$\begin{aligned} \text{sgn}(t) & \quad (1/j\pi f) \\ (1/\pi t) & \quad -j \text{sgn}(f) \\ U(t) & \quad \frac{1}{2} \delta(f) + \frac{1}{j2\pi f} \end{aligned}$$

Even function odd function

$$\sum_{n=-\infty}^{\infty} \delta(t-nT_0) \quad \frac{1}{T_0} \sum_{n=-\infty}^{\infty} \delta\left(f-\frac{n}{T_0}\right)$$

3.8 DISCRETE TIME FOURIER TRANSFORM

The Discrete-Time Fourier Transform (DTFT)

Consider the general discrete-time sequence $x[n]$ of finite duration, i.e.,

$$\begin{aligned} x[n] & \neq 0; & \text{for } -N_1 \leq n \leq N_2 \\ & = 0; & \text{otherwise} \end{aligned}$$

DTFT of $x[n]$

$$X(e^{j\omega}) = \sum_{n=-\infty}^{\infty} x[n] e^{-j\omega n}$$

This is called *DTFT Analysis equation* and

$$x[n] = \frac{1}{2\pi} \int_{-\pi}^{\pi} X(e^{j\omega}) e^{j\omega n} d\omega$$

This is called *DTFT synthesis equation*.

- DTFT gives continuous and periodic spectrum but DFT gives a discrete and a periodic spectrum.
- DTFT of a discrete time sequence $x[n]$ is obtained by performing the sampling operation in time domain only.

There are many similarities between DTFT and CTFT such as linearity, convolution, etc., The major difference between them are:

- DTFT is periodic in ω with period 2π and continues but CTFT is not periodic.
- DTFT has finite interval of integration in the synthesis equation but CTFT has infinite interval of integration in the synthesis equation.

Discrete Time Fourier Transform of Periodic Signal

Consider the signal

$$x(t) = e^{-j\omega_0 t}$$

$$X(\omega) = 2\pi \delta(\omega - \omega_0)$$

$$x[n] = e^{j\omega n}$$

$$X(e^{j\omega}) = \sum_{m=-\infty}^{\infty} 2\pi \delta(\omega - \omega_o - 2\pi m)$$

$$\text{Therefore, } x[n] = \sum_{k=-\infty}^{\infty} a_k e^{jk\omega_o n}$$

$$X(e^{j\omega}) = \sum_{k=-\infty}^{\infty} 2\pi a_k \delta\left(\omega - \frac{2\pi k}{N_o}\right)$$

3.9 DFT (DISCRETE FOURIER TRANSFORM)

Fourier transform of discrete-time signal $x[n]$ is called *Discrete-time Fourier transform (DTFT)* and denoted by $X(\omega)$. DTFT $X(\omega)$ is a continuous function of frequency (ω). Therefore, this representation is not a computationally convenient representation of $\{x[n]\}$. We represent a sequence by samples of its continuous spectrum. This frequency domain representation of a signal is called *Discrete Fourier Transform*.

- The DFT is itself a sequence rather than a function of continuous variable and it corresponds to equally spaced frequency sample of the Discrete-Time Fourier Transform (DTFT) of a signal.
- DFT plays a central role in the implementation of various DSP algorithms.
- Fourier series representation of the periodic sequence corresponds to the Discrete Fourier transform (DFT) of the finite length sequence.
- DFT is used for transforming discrete-time sequence $x[n]$ of finite length into discrete-frequency sequence $X(k)$ of finite length. By DFT, discrete-time sequence $x[n]$ is transformed into corresponding discrete-frequency sequence $X(k)$
- Discrete Fourier transform (DFT) of a discrete-time-square $x[n]$ is obtained by performing the sampling operation in both the time and frequency domains.
- DFT of a discrete-time sequence $x[n]$ is related to DTFT of same sequence by

$$X[k] = X(e^{j\omega}) \Big|_{\omega=2\pi k/N}$$

Where, $X(k)$ is the DFT of $x(n)$ and is given by

$$= X(k) = \sum_{n=-\infty}^{\infty} x[n] e^{-j\pi k n/N}$$

3.10 FFT

Fast Fourier Transform (FFT)

The fast Fourier transform (FET) is a method (or algorithm) for computing the discrete Fourier transform (DET) with reduced number of calculations. The computational efficiency is achieved

if we adopt a divide and conquer approach. This approach is based on the decomposition of an N -point DFT into successively smaller DFTs. This basic approach leads to a family of an efficient computational algorithms known collectively as FFT algorithms.

Radix-r FFT

In an N -point sequence, if N can be expressed as $N = r^m$, then the sequence can be decimated into r -point sequence. For each r -point sequence, r -point DFT can be computed. From the results of r -point DFT, the r^2 -point DFTs are computed. From the results of r^2 -point DFTs, the r^3 -point DFTs are computed and so on, until we get r^m point DFT. This FFT algorithm is called radix- r FFT. In computing N -point DFT by this method, the number of stages of computation will be m times.

Radix-2 FFT

For radix-2 FFT, the value of N should be such that, $N = 2^m$, so that the N -point sequence is decimated into 2-point sequence and the 2-point DET for each decimated sequence is computed. From the results of 2-point DFTs, the 4-point DFTs can be computed. From the results of 4-point DFTs, the 8-point DFT can be computed and so on, until we get N -point DFT.

Number of Calculation in N-point DFT

Let, $X(k)$ be N -point DFT of an L -point discrete time sequence $x(n)$, where, $N \geq L$. Now, the N -point DFT is a sequence consisting of N -complex number. Each complex number of the sequence is calculated using the following equation (1)

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-\frac{j2\pi kn}{N}}; \text{ for } K = 0, 1, 2, \dots, (N-1)$$

$$= \begin{bmatrix} x(0)e^0 + x(1)e^{-\frac{j2\pi k}{N}} + x(2)e^{-\frac{j4\pi k}{N}} \\ + x(3)e^{-\frac{j6\pi k}{N}} + \dots + x(N-1)e^{-\frac{j2(N-1)\pi k}{N}} \end{bmatrix}$$

The computation of above equation for one value of k involves N number of complex multiplications and $N-1$ number of complex additions. Therefore, the computation of all N values of the sequence $X(k)$ involves $N \times N = N^2$ complex multiplications and $N \times (N-1)$ complex additions. Hence, in direct computation of N -point DFT, the total number of complex additions are $N(N-1)$ and total number of complex multiplications are N^2 .

3.11 Z-TRANSFORM

Z-transform provides the solution for linear constant coefficient differential equations relating discrete time system in the frequency domain.

$$H(s) = \frac{K(s-Z_1)(s-Z_2)(s-Z_3)\dots}{(s-P_1)(s-P_2)(s-P_3)\dots}$$

where, K is constant

$$S = j\omega \text{ and } 0 \leq \omega \leq$$

P_1, P_2, P_3 ----are poles

Z_1, Z_2, Z_3 ----are zero

$$H(z) = \frac{K(z-z_1)(z-z_2)(z-z_3)}{(z-p_1)(z-p_2)(z-p_3)}$$

Under this mapping, the imaginary axis $\sigma = 0$ maps on to the unit circle $|Z| = 1$ in the Z -plane. Also the LHS of s -plane i.e., $\sigma < 0$ corresponds to the interior of the unit circle $|Z| = 1$ in the s -plane.

$$X[z] = \sum_{n=0}^{\infty} x[n] e^{-n}$$

Note: Z-transform method is used to analyze discrete time system for finding the transfer function, stability and digital network realization of the system.

Region of Convergence (ROC)

$$X[z] = \sum_{n=0}^{\infty} x[n] z^{-n}$$

$$X[z] \Big|_{z=r e^{j\omega}} = X(r e^{j\omega}) = \sum_{n=-\infty}^{\infty} x[n] r^{-n} e^{-j\omega n}$$

Which is the fourier transform of the modified sequence $[x[n] r^{-n}]$.

If $r = 1$ i.e., $|Z| = 1$

$X[z]$ reduces to its fourier transform

The series of the above equation converges if $x[n] r^{-n}$ is absolutely sum able i.e.,

$$= \sum_{n=0}^{\infty} x[n] |r^{-n}| < \infty$$

If the output signal magnitude of the digital signal system $x[n]$ is to be finite, the magnitude of z -transform $X[z]$ must be finite. The set of Z -Value in the Z -Plane for which the magnitude of $X[z]$ is finite is called the region of convergence (ROC).

Therefore, the condition for $X[z]$ to be finite is $|z| > 1$. In other words, the ROC of $X[z]$ is the area outside the unit circle in the z -plane.

The ROC of a rational Z -transform is bounded by the location of its poles.

(a) Important properties of the ROC of Z-transform

1. $X[z]$ converges uniformly if and only if the ROC of Z -transform $X[z]$ of the sequence includes the unit circle

$$= \sum_{n=-\infty}^{\infty} |x[n] r^{-n}| < \infty.$$

2. The ROC does not contain any pole.

3. When $x[n]$ is of finite duration, the ROC is the entire z -plane except possibly $z = 0$ and/or $z = \infty$.
4. If $x[n]$ is right sided sequence, the ROC will not include infinity.
5. If $x[n]$ is left sided sequence, the ROC will not include $z = 0$. However, if $x[n] = 0$ for all $n > 0$, then ROC will include $z = 0$.
6. If $x[n]$ is two sided, and if the circle $|z| = r_o$ is in the ROC, then ROC will consist of ring in the z -plane that includes the circle $|z| = r_o$, that is the ROC includes the intersection of ROC of the component.
7. If $X[z]$ is rational, then the ROC extends to infinity i.e., ROC is bounded by poles.
8. If $x[n]$ is causal, then the ROC include $z = \infty$ except $z = 0$.
9. If $x[n]$ is anti casual, the ROC include $z = 0$ except $z = \infty$.

(b) Properties of Z-transform:

(i) Linearity: If it is homogenous and satifies super position

$$\text{If } x[n] = A_1 x_1[n] + A_2 x_2[n]$$

$$X[z] = A_1 X_1[z] + A_2 X_2[z]$$

$$\text{With ROC} = R_1 \text{ and } R_2$$

$$R = R_1 \cap R_2$$

(ii) Time shifting

$$\text{if } x[n] \rightarrow X[z] \text{ with ROC} = R$$

$$\text{Then } x[n-k] \rightarrow X[z] z^{-k}$$

With ROC = R except addition or deletion of the origin or infinity

If for $k > 0$ -----origin deleted

$k < 0$ ----- infinity deleted

(iii) Scaling

$$\text{If } x[n] \rightarrow X[z] \text{ with ROC} = R$$

$$A^n x[n] \rightarrow X[Z/A] \text{ with ROC} = [A | R].$$

(iv) Time Reversal

$$x[n] \rightarrow X[z] \text{ with ROC} = R$$

$$x[-n] \rightarrow X[1/z] \text{ with ROC} = [1/R]$$

(v) Time Expansion

$$x[n] \rightarrow X[z]; \text{ ROC} = R$$

$$x_k[n] = \begin{cases} x[n/k] & ; \text{ if } n \text{ is multiple of } k \\ 0 & ; \text{ if } n \text{ is not multiple of } k \end{cases}$$

$$x_k[n] \rightarrow X[z^k] \text{ with ROC} = R^{(1/k)}$$

(vi) Differentiation in Z-Domain

$$x[n] \rightarrow X[z]$$

$$n x[n] \rightarrow -\frac{z d X[z]}{dz}$$

$$\rightarrow z^{-1} \frac{d X[z]}{d z^{-1}}$$

With ROC = same

(1) Convolution

$$x_1[n] \rightarrow X_1[z]; \text{ ROC} = R_1$$

$$x_2[n] \rightarrow X_2[z]; \text{ ROC} = R_2$$

$$x[n] = x_1[n] * x_2[n] = \sum_{k=-\infty}^n x_1[k] x_2[n-k]$$

$$= X_1[z] \cdot X_2[z]; \text{ ROC} = R_1 \cap R_2$$

(2) Correlation

$$x_1[n] \rightarrow X_1[z]; \text{ ROC} = R_1$$

$$x_2[n] \rightarrow X_2[z]; \text{ ROC} = R_2$$

$$r_{x_1 x_2}[p] = \sum_{n=-\infty}^{\infty} x_1[n] x_2[n-p]$$

$$R_{x_1 x_2}[z] = X_1[z] X_2[z^{-1}]; \text{ ROC} = R_1 \cap R_2$$

(3) Auto correlation

$$x_1[n] = x_2[n]$$

$$X[z] = X_1[z] X_1[z^{-1}]$$

(vii) Initial value theorem

If $x[n] = 0$, for $n < 0$ i.e., $x[n]$ is casual

The initial value is given by

$$x[0] = \lim_{n \rightarrow 0} x[n] = \lim_{|z| \rightarrow \infty} X[z]$$

(viii) Final value Theorem

If $X[z] = ZT(x[n])$ and the poles of $X[z]$ are all inside the unit circle

$$x(\infty) = \lim_{n \rightarrow \infty} x[n] = \lim_{|z| \rightarrow 1} (1 - z^{-1}) X[z]$$

One sided Z-transform.

(1) Time delay

$$x[n] \rightarrow X[z]$$

$$x[n-k] \rightarrow z^{-k} \left(X[z] + \sum_{n=1}^k x[-n] z^n \right) k > 0$$

(2) Time Advance

$$x[n] \rightarrow X[z]$$

$$x[n+k] \rightarrow z^{-k} \left(X[z] - \sum_{n=0}^{k-1} x[n] z^{-n} \right)$$

Evaluation of Inverse Z-transform

$$x[n] = \frac{1}{2\pi j} \oint_C X[z] z^{n-1} dz \dots$$

The above equation represents a contour integral over a closed path C that encloses the origin and lies within the ROC of $X[z]$.

Long Division Method

The Z-transform of a signal or system which is expressed as the ratio of two polynomials in Z , is simply divided out to produce a power series in the form of an equation

$$X[z] = \sum_{n=0}^{\infty} x[n] z^{-n} = \sum_{n=0}^{\infty} a_n z^{-n} = \frac{N[z]}{D[z]}$$

$$= a z^0 + a_1 z^{-1} + a_2 z^{-2} + \dots \text{ is not a closed form.}$$

Solution:

Where the coefficient a_n are the value of $x[n]$.

Thus, the coefficient z^{-k} is the k^{th} term in the sequence. The ROC will determine whether the series has positive or negative exponents.

RH sequence $\rightarrow$ Primarily negative exponents

LH sequence $\rightarrow$ Positive exponents

3.12 SAMPLING THEOREM

Modulating signal = $f(t)$; $m(t)$.

Sampling signal carrier = $f_s(t)$, i.e., pulse train or impulse train (for pulse modulation)

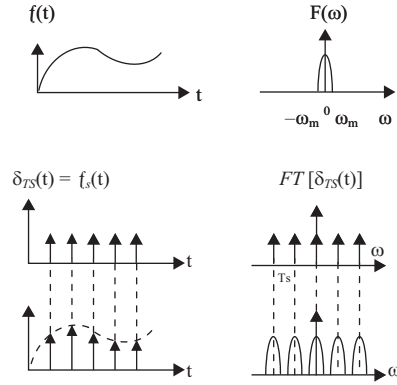


Fig. 3.14

$f(t) \rightarrow$ Modulating signal is a band limited signal with highest modulating frequency component of frequency or ω_m .

$$f(t) = \delta_{TS}(t) = \sum_{n=-\infty}^{\infty} \delta(t - n T_s)$$

$$= P_{TS}(t) = \sum_{n=-\infty}^{\infty} P(t - n T_s)$$

Hence in order to recover the signal from its sample version, we must have $f_s \geq 2f_m$.

$$f_{s(\min)} \text{ Nyquist rate} = 2f_m = 2\omega_m$$

$$\text{or } T = (1/2f_m)$$

The maximum interval of Sampling is known as **Nyquist interval**.

Statement of Sampling Theorem

1. **Frequency domain statement:** A band limited signal of finite energy which has no frequency components higher than f_m Hz is completely described by specifying the value of signal at the instant of time separated by

$$T_s = \left(\frac{1}{2f_m} \right) = \left(\frac{1}{2\omega_m} \right) \text{ sec.}$$

Sampling Theorem Mathematical Proof

The $f(t)$ is band limited signal which is limited to frequency $\pm \omega_m$.

$$\text{Let, } f(t) \leftrightarrow F(\omega)$$

$$\text{Also } \delta_{TS}(t) = \text{Sampling signal}$$

$$F_s(\omega) = \omega_o \sum_{n=-\infty}^{\infty} F(\omega - n \omega_o).$$

Aliasing Effect

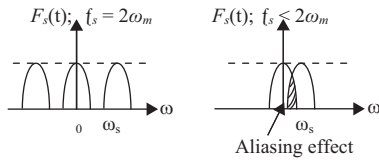


Fig. 3.15

The phenomena of high frequency component in the Spectrum of the original signal $f(t)$ effectively taking on the identity of lower frequency component in the spectrum of its sampled version is called the *Aliasing effect*.

3.13 LINEAR TIME-INVARIANT (LTI) SYSTEMS, DEFINITIONS AND PROPERTIES, CAUSALITY, STABILITY, IMPULSE RESPONSE, CONVOLUTION, POLES AND ZEROS

Linear time-Invariant system

LTI system possess is the superposition property. If we can represent the input to a LTI system in terms of linear combination of a set basic signal, we can then use superposition to compute the output of system in term of its response to there basic signals.

Continuous-Time and Discrete-Time (LTI) System

- A system which possesses two properties namely linearity and time invariance is called linear time invariant (LTI) system.
- These two properties, linearity and time invariance, play a fundamental role in signal and system analysis. Many physical processes have these properties and thus can be modeled as linear time invariant (LTI) system. LTI systems can be analyzed in adequate detail with the help of a set of powerful tools which are already available. These tolls are the basis of signal and system analysis.
- LTI systems are of two types viz., continuous time and discrete-time. One of the primary reasons why linear time invariant (LTI) systems are amenable to analysis is that any such system has the super position property. LTI systems are characterized by their impulse response in both continuous time and discrete time and these are represented as linear combinations of delayed impulses.
- The complete characterization of any LTI system in terms of its impulse response is performed by convolution integral in the continuous time case and by the convolution sum indiscrete time case.
- A continuous time LTI system is described by linear constant-coefficient differential equations.
- Similarly, a described-time (LTI) system is described by linear constant coefficient difference equations.

Continuous Time Linear Time Invariant System

A system of which both input and output are continuous time signals and possesses two properties namely linearity and time invariance is referred to as continuous time linear time invariant (LTI) system.

These systems are characterized either by their impulse response $h(t)$ or by their transfer function $H(s)$.

Continuous time signals are represented mathematically as the superposition of scaled and shifted continuous time unit impulse functions $\delta(t)$.

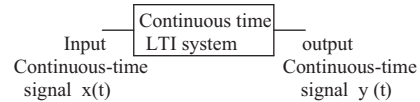


Fig. 3.16 Time Shifted Impulse Response

Continuous time input signal $x(t)$ is represented in terms of $\delta(t)$ as

$$x(t) = \int_{-\infty}^{\infty} x(\tau) \delta(t - \tau) d\tau$$

Continuous time impulse response $h(t)$ is the output of a continuous time system when applied input $x(t)$ is equal to unit impulse function $\delta(t)$.

Transfer function of a continuous time LTI system is the ratio of Laplace transform of output $y(t)$ and Laplace transform of input $x(t)$ of a system when the system is initially relaxed. For an initially relaxed system, all the initial conditions are zero.

Unit Impulse Response for Continuous Time LTI Systems

Output of a continuous time LTI system is called unit impulse response when we apply an input equal to unit impulse function $\delta(t)$.

If input $x(t) = \delta(t)$ is unit impulse function then output $y(t) = h(t)$ is unit impulse response where unit impulse function $\delta(t)$ is given by

$$\delta(t) = \begin{cases} 1, & t = 0 \\ 0, & t \neq 0 \end{cases}$$

Transfer function of continuous time LTI system is equal to Laplace transform of unit impulse response of a continuous time LTI system.

Transfer function of a continuous time LTI system

$H(s)$ = Laplace transform of $h(t)$.

$$= \text{LT} [h(t)] = \int_{-\infty}^{\infty} h(t) e^{-st} dt$$

where, s is a complex variable and $s = \sigma + j\omega$, σ real part and ω imaginary part.

Properties of Continuous Time and Discrete Time LTI Systems

We know that continuous time and discrete time systems are characterized by their unit impulse responses. Response of continuous time LTI system is determined by using convolution integral.

While the response of discrete time LTI system is determined by using convolution sum.

Now we will discuss various properties of continuous time and discrete time LTI systems.

Convolution integral for continuous time LTI is given by $y(t) = x(t) * h(t) = \int_{-\infty}^{\infty} x(\tau) h(t - \tau) d\tau$ and convolution sum for discrete time LTI system is given by $y[n] = x[n] * h[n] = \sum_{K=-\infty}^{\infty} x(k) h(n - k)$

Both continuous time and discrete time LTI systems are completely characterized by their impulse responses. These systems are also completely characterized by their transfer function. For continuous time LTI system, the transfer function is the ratio of Laplace transform of output to Laplace transform of input to the system when system is initially relaxed. It is also defined as Laplace transform of impulse response of a continuous time LTI system.

For discrete time LTI system, transfer function is the ratio of z -transform of output to z -transform of input when initially system is relaxed. It is also defined as z -transform of unit impulse response of discrete time LTI system.

Causality for LTI Systems

The output of a causal system depends only on the present and past values of the input to the system.

A continuous tie LTI system is called causal system if its impulse response $h(t)$ is zero for $t < 0$.

For a causal continuous time LTI system, convolution integral is given by

$$\begin{aligned} y(t) &= x(t) * h(t) = \int_{\tau=-\infty}^{\infty} x(\tau) h(t - \tau) d\tau \\ &= h[n] * x[n] = \sum_{k=0}^{\infty} h(k) x(n - k) \end{aligned}$$

Causality of an LTI system is equivalent to its impulse response being a causal signal. Accumulator with impulse response

$$h[n] = u[n] = \begin{cases} 0 & n < 0 \\ 1 & n \geq 0 \end{cases}$$

is a causal discrete time LTI system.

A pure time shift with unit impulse response $h(t) = \delta(t - t_o)$ is a causal continuous time LTI system for $t \geq 0$. In this case time shift is called a delay.

A pure time shift is non causal continuous time LTI system for $t < 0$. In this case time shift is called an advance.

Stability for LTI Systems

A stable system produces bounded output from every bounded input.

Condition of stability for continuous time LTI system: Consider an input $x(t)$ that is bounded in magnitude

Linear Time Invariant Systems (LTI)

Impulse Response

The unit sample response or simply the impulse response $h[n]$ of a linear time invariant system is the system's response to a unit impulse input signal $\{\delta[n]\}$ located at $n = 0$, when the initial conditions of the system are zero.

$$\delta[n] = \begin{cases} 1 & n = 0 \\ 0 & n \neq 0 \end{cases}$$

Impulse Response of Linear Time Invariant Causal (LTIC) System

If the input to the system is the time shifted version of the $d(t)$ function, the output is a time shifted version of the impulse response. The result shown in figure is due to the impulse response and time invariance of the system. In the linear system, application of $\alpha d(n - k)$ at the input will produce a $h(n - k)$ at the output as shown in the figure.

$$\begin{array}{ccc} x[n] & \xrightarrow{\text{LTIC System}} & y[n] \\ \alpha \delta[n-k] & & \alpha h[n-k] \end{array}$$

Fig. 3.17 Time shifted impulse response

The shifted impulse sequence is given by

$$= x[n] * h[n]$$

$$y[n] = \sum_{k=-\infty}^{\infty} h(k) x(n - k) = h[n] * x[n]$$

This expression gives the output response $y[n]$ of the LTI system as a function of the input signal $x[n]$ and the unit impulse (sample) response $h[n]$ and is referred to as a **convolution sum**.

Unit step Response $\{u[n]\}$

The unit step sequence $u[n]$ is defined by

$$u[n] = \begin{cases} 0 & n < 0 \\ 1 & n \geq 0 \end{cases}$$

The shifted unit step sequence $u(n - k)$ is given by

$$u[n - k] = \begin{cases} 0 & n < 0 \\ 1 & n \geq 0 \end{cases}$$

The graphical representations of $u[n]$ and $u(n - 2)$ are shown in figure.

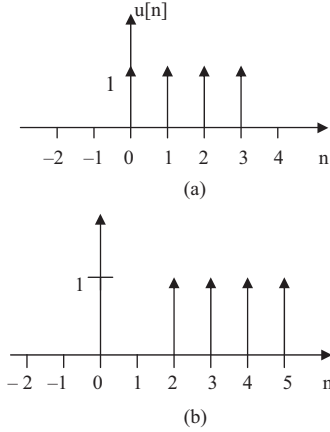


Fig. 3.18 (a) The Unit-step Sequence $u[n]$ $u[n-2]$
(b) The shifted Unit-step Sequence $u[n-2]$

The step response can be obtained by exciting the input of the system by a unit-step sequence, i.e., $x[n] = u[n]$. Hence, the output response $y[n]$ is obtained by using the convolution formula as

$$y[n] = \sum_{m=0}^n h(k) u(n-k)$$

Relation Between the Unit Sample and the Unit-Step Sequence

The unit sample sequence $\delta[n]$ and the unit-step sequence $u[n]$ are related as

$$u[n] = \sum_{m=-\infty}^{\infty} \delta[m]$$

$$\delta[n] = u[n] - u[n-1]$$

Properties of LTI System

1. Causality

Causal system are those in which changes in the output are dependent only on the present and the past values of the input and/or previous output values, and are not dependent on future input values. For a linear time invariant system, the causality condition is given by:

$$h[n] = 0 \text{ for } n < 0.$$

2. Stability

The transfer function of the discrete time system is a rational function of z with real coefficients. For causal filters, the degree of the numerator polynomial is equal to or less than that of the denominator polynomial. The poles of the transfer function $H(z)$ determine whether the filter is stable or not, as in analog system.

A necessary and sufficient condition for a LTI system to be stable is that the poles of the transfer function $H(z)$, $|p_i| < 1$ for $i = 1, 2, \dots, N$, i.e.,

$$\sum_{n=-\infty}^{\infty} |h[n]| < \infty$$

3.14 POLES AND ZEROS

In most practical discrete-time systems, the Z-transform, that is, the system transfer function $H(z)$, can be expressed in terms of its poles and zeros. Consider, for example, the following z-transform representing a general, N th-order discrete-time filter (where $N = M$)

$$H(z) = \frac{N(z)}{D(z)} \quad (1)$$

where,

$$N(z) = b_0 z^N + b_1 z^{N-1} + b_2 z^{N-2} + \dots + b_N$$

$$D(z) = a_0 z^N + a_1 z^{N-1} + a_2 z^{N-2} + \dots + a_N$$

Then a_k and b_k are the coefficients of the filter.

If $H(z)$ has poles at $z = p_1, p_2, \dots, p_N$ and zeros at $z = z_1, z_2, \dots, z_N$, then $H(z)$ can be factored and represented as

$$H(z) = \frac{K(z-z_1)(z-z_2)\dots(z-z_N)}{(z-p_1)(z-p_2)\dots(z-p_N)} \quad (2)$$

The information contained in the Z-transform can be conveniently displayed as a pole-zero diagram, see figure for example.

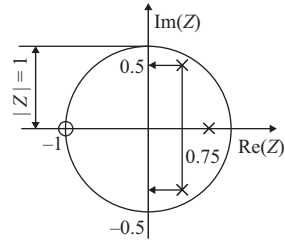


Fig. 3.19 Description of z-transform in the form of a pole-zero diagram: X pole, O zero.

In the diagram, X marks the position of a pole and O denotes the position of zero. For example, poles are located at $z = 0.5 \pm 0.5j$ and $z = 0.75$. A single zero is at $z = -1$.

3.15 PARALLEL STRUCTURE

Parallel Connection

If there are L number of linear time invariant system in the time-domain connected in parallel, the impulse response $h[n]$ of the resultant system is given by

$$h[n] = \sum_{k=1}^L h_k[n]$$

Where, $h_k[n]$, $k = 1, 2, \dots, L$ is the impulse response of the individual system. By using the linearity property of the z-transform, the frequency response of the overall system is

$$H(z) = \sum_{k=1}^L H_k(z) = H_1(z) + H_2(z) + \dots + H_L(z)$$

Where, $z = e^{j\omega}$. Here $H_k(e^{j\omega})$ is the frequency response to the impulse response $h_k[n]$.

From the above discussion, it is clear that the parallel interconnection of system involves additivity in both the time and frequency domain.

3.16 CASCADE STRUCTURE

Cascade Connection

If the L linear time invariant systems are connected in cascade, the impulse response of the overall system is

$$h[n] = h_1[n] * h_2[n] * \dots * h_L[n]$$

Using the convolution property of the z-transform, we get

$$H(z) = H_1(z) H_2(z) \dots H_L(z)$$

$$\text{Hence, } H(e^{j\omega}) = H_1(e^{j\omega}) H_2(e^{j\omega}) \dots H_L(e^{j\omega})$$

Here we have observed that the cascade connection involves convolution of the impulse responses in the time domain and multiplication of the frequency domain.

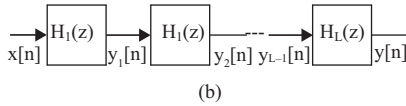


Fig. 3.20 Cascade Interconnection of Linear Discrete Time Systems

3.17 FREQUENCY RESPONSE

Frequency response is a complex function that describes the magnitude and phase shift of a filter over a range of frequencies.

(Response to complex exponential and sinusoidal signals)

Response of any linear time invariant system to an arbitrary input signal $x(n)$, is given by convolution sum formula,

$$y(n) = \sum_{K=-\infty}^{\infty} h(K) \cdot x(n-K)$$

Now let us given input as a complex exponential

$$x(n) = Ae^{j\omega n}$$

Then $y(n)$ will become

$$\begin{aligned} y(n) &= \sum_{K=-\infty}^{\infty} h(K) [Ae^{j\omega(h-K)}] \\ &= A \left[\sum_{K=-\infty}^{\infty} h(K) \cdot e^{j\omega K} \right] e^{j\omega n} \end{aligned}$$

$$H(\omega) = \sum_{K=-\infty}^{\infty} h(K) \cdot e^{j\omega K}$$

$$y(n) = AH(\omega) e^{j\omega n}$$

Thus we can say that frequency of input and output are same only amplitude and phase changes.

Properties of the Frequency Response

If $h[n]$ is a real sequence, the frequency response has the following properties:

- $H(e^{j\omega})$ takes on values for all ω , i.e., on a continuum of ω .
- $H(e^{j\omega})$ is periodic in ω with period 2π .
- The magnitude response $|H(e^{j\omega})|$ is an even functions of ω and symmetrical about π .
- The phase response $\angle H(e^{j\omega})$ is an odd function of ω and antisymmetrical about π .

3.18 GROUP DELAY

Group Delay

Let the dispersive channel is described by the transfer function $H(f) = ke^{j\beta(f)}$, where, the phase $\beta(f)$ is a non-linear function of frequency. The input signal $x(t)$ consists of a narrow-band signal defined by

$$x(t) = x_c(t) \cdot \cos(2\pi f_c t)$$

Expanding $\beta(f)$ by Taylor's series at the point $f=f_c$ only two terms,

$$\beta(f) \cong \beta(f_c) + (f - f_c) \left. \frac{\partial \beta(f)}{\partial f} \right|_{f=f_c}$$

$$\text{Define, } \tau_p = -\frac{\beta(f_c)}{2\pi f_c}$$

$$\tau_g = -\frac{1}{2\pi} \left. \frac{\partial \beta(f)}{\partial f} \right|_{f=f_c}$$

3.19 PHASE DELAY

Let a sinusoidal signal at frequency f_c is transmission through a dispersive channel which has a total phase-shift of $\beta(f_c)$ radians at that frequency. The time taken by the received signal phase to sweep out this phase lag is simply equal to $[\beta(f_c)/(2\pi f_c)]$ second (phase delay).

Magnitude Response and Phase Response of Digital, i.e., Phase Delay and Group Delay

The discrete-time fourier transform of a finite sequence impulse response $h[n]$ is given by:

$$H(e^{j\omega}) = \sum_{n=0}^{M-1} h[n] e^{-j\omega n} = |H(e^{j\omega})| e^{j\phi(\omega)}$$

The magnitude and phase response are given by:

$$M(\omega) = |H(e^{j\omega})| = [\text{Re}\{H(e^{j\omega})\}^2 + \text{Im}\{H(e^{j\omega})\}^2]^{0.5}$$

$$\phi(\omega) = \tan^{-1} \frac{\text{Im}[H(e^{j\omega})]}{\text{Re}[H(e^{j\omega})]}$$

Filter can have a linear or non-linear phase depending upon the delay function, namely the phase delay and group delay. The phase and group of the filter are given by

$$\tau_p = \frac{-\phi(\omega)}{\omega}$$

and $\tau_g = \frac{-d\phi(\omega)}{d\omega}$, respectively

3.20 SIGNAL TRANSMISSION THROUGH LTI SYSTEMS

Signal Transmission Through LTI System

Two conditions must be met to allow distortionless transmission through system:

1. A system must attenuate all of the frequency components equally i.e., $|H(\omega)|$ should have constant magnitude for all frequencies.
2. Phase characteristic of a system must be linear.

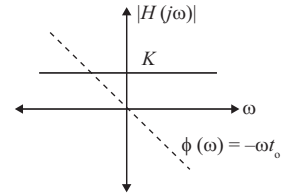


Fig. 3.21

QUESTION BANK

LEVEL 1

1. Double integration of a unit step function would lead to
 - (a) an impulse
 - (b) a parabola
 - (c) a ramp
 - (d) a doublet
2. The Fourier transform of a Gaussian time pulse is
 - (a) uniform
 - (b) a pair of impulses
 - (c) Gaussian
 - (d) Raleigh
3. The Laplace transformation method enables one to find the response of a network in
 - (a) the transient state only
 - (b) the steady state only
 - (c) both transient and steady states
 - (d) the transient state provided sinusoidal forcing function do not exist
4. The impulse response of a single-pole system would approach a non-zero constant as $t \rightarrow \infty$ if and only if the pole is located in the s -plane
 - (a) on the negative real axis
 - (b) at the origin
 - (c) on the positive real axis
 - (d) on the imaginary axis
5. Consider the following statements regarding the fundamental component $f_1(t)$ of an arbitrary periodic signal $f(t)$
It is possible for
 1. The amplitude of $f_1(t)$ to exceed the peak value of $f(t)$
 2. $F_1(t)$ to be identically zero for a non-zero $f(t)$
 3. The effective value of $f_1(t)$
 Which of these statements is/are correct?
 - (a) 1 alone
 - (b) 1 and 2
 - (c) 2 and 3
 - (d) 1 and 3
6. Consider the following statements related to Fourier series of a periodic waveform:
 1. It expresses the given periodic waveform as combination of d.c component, sine and waveforms of different harmonic frequencies
 2. The amplitude spectrum is discrete
 3. The evaluation of Fourier coefficients gets simplified if waveform symmetries are used
 4. The amplitude spectrum is continuous
 Which of the above statements are correct?
 - (a) 1, 2 and 4
 - (b) 2, 3 and 4
 - (c) 1, 3 and 4
 - (d) 1, 2 and 3
7. Consider the following statements:
 1. Fourier transform is special case of Laplace transform
 2. Region of convergence need not be specified for Fourier transform
 3. Laplace transform is not unique unless the region of convergence is specified
 4. Laplace transform is a special case of Fourier transform
 Which of these statements are correct?
 - (a) 2 and 4
 - (b) 4 and 1
 - (c) 4, 3 and 2
 - (d) 1, 2 and 3
8. The units of the spectrum obtained by Fourier transforming the covariance function of a stationary stochastic process is
 - (a) power per Hertz
 - (b) energy per Hertz
 - (c) power per second
 - (d) energy per second
9. Consider the following statements associated with the Superposition theorem?
 1. It is applicable to dc circuits only
 2. It can be used to determine the current in a branch or voltage across a branch
 3. It is applicable to networks consisting of more than one source
 4. It is applicable to network consisting of linear and bilateral elements
 Which of these statements are correct?
 - (a) 1, 2 and 3
 - (b) 2, 3 and 4
 - (c) 3, 4 and 1
 - (d) 4, 1 and 2
10. The sum of two or more arbitrary sinusoids is
 - (a) Always periodic
 - (b) Periodic under certain conditions
 - (c) Never periodic
 - (d) Periodic only if all the sinusoids are identical in frequency and phase
11. The impulse response of a linear time invariant system is a rectangular pulse of duration T . It is excited by an input of a pulse of duration T . What is the filter output waveform?
 - (a) Rectangular pulse of duration T
 - (b) Rectangular pulse of duration $2T$
 - (c) Triangular pulse of duration T
 - (d) Triangular pulse of duration $2T$
12. If the response of a system to an input does not depend on the future values of the input, then which one of the following is true for the system?
 - (a) It is aperiodic
 - (b) It is causal
 - (c) It is anticipatory
 - (d) It is discrete
13. What does the transfer function of a system describe for the system?
 - (a) Only zero-input response
 - (b) Only zero-state response
 - (c) Both zero input and zero-state responses
 - (d) Neither zero-input response nor zero-state response

3.20 ■ Signals and Systems

14. Which one of the following is the correct statement? The continuous time system described by $Y(t) = x(t^2)$ is
 - (a) causal, linear and time-varying
 - (b) causal, non-linear and time-varying
 - (c) non-causal, non-linear and time-invariant
 - (d) non-causal and time-variant
15. An excitation is applied to a system at $t = T$ and its response is zero for $-\infty < t < T$. Such a system is
 - (a) non-causal system
 - (b) stable system
 - (c) causal system
 - (d) unstable system
16. Which of the following signals is non-periodic?
 - (a) $s(t) = \cos 2t + \cos 3t + \cos 5t$
 - (b) $s(t) = \exp(j8\pi t)$
 - (c) $s(t) = \exp(-7t) \sin 10\pi t$
 - (d) $s(t) = \cos 2t \cos 4t$
17. If $G(f)$ represents the Fourier transform of a signal $g(t)$ which is real and odd symmetric in time, then
 - (a) $G(f)$ is complex
 - (b) $G(f)$ is imaginary
 - (c) $G(f)$ is real
 - (d) $G(f)$ is real and non-negative
18. If $F(s) = FT[f(t)]$ and $sF(s) = \frac{K}{(s+1)(s^2+4)}$ the $\lim_{t \rightarrow \infty} f(t)$
 - (a) $K/4$
 - (b) zero
 - (c) infinite
 - (d) undefined
19. The Fourier Series of an odd periodic function, contains only
 - (a) odd harmonics
 - (b) even harmonics
 - (c) cosine terms
 - (d) sine terms
20. The trigonometric Fourier series of an even function of time does not have
 - (a) dc term
 - (b) cosine terms
 - (c) sine terms
 - (d) odd harmonic terms
21. The Fourier transform of a real valued time signal has
 - (a) Odd symmetry
 - (b) Even symmetry
 - (c) Conjugate symmetry
 - (d) Symmetry
22. The autocorrelation function of an energy signal has
 - (a) no symmetry
 - (b) conjugate symmetry
 - (c) odd symmetry
 - (d) even symmetry
23. The power spectral density of a deterministic signal is given $[\sin(f)/f]^2$ where f is frequency
 The autocorrelation function of this signal in the time domain is
 - (a) A rectangular pulse
 - (b) A delta function
 - (c) A sine pulse
 - (d) A triangular pulse
24. The spectral density of a real valued random process has
 - (a) An even symmetry
 - (b) An odd symmetry
 - (c) A conjugate symmetry
 - (d) No symmetry
25. The probability density function of the envelope of narrow-band Gaussian noise in
 - (a) Poisson
 - (b) Gaussian
 - (c) Rayleigh
 - (d) Rician
26. If $[f(t)] = F(s)$, then $[f(t-T)]$ is equal to
 - (a) $e^{sT} F(s)$
 - (b) $e^{-sT} F(s)$
 - (c) $\frac{F(s)}{1+e^{sT}}$
 - (d) $\frac{F(s)}{1-e^{-sT}}$
27. A signal $x(t)$ has a Fourier transform $X(\omega)$. If $x(t)$ is a real and odd function of t , then $X(\omega)$ is
 - (a) A real and even function of ω
 - (b) An imaginary and odd function of ω
 - (c) An imaginary and even function of ω
 - (d) A real and odd function of ω
28. The impulse response $h[n]$ of a linear time-invariant system is given by
 $h[n] = u[n+3] + u[n-2] - 2u[n-7]$
 where $u[n]$ is the unit step sequence. The above system is
 - (a) Stable but not causal
 - (b) Stable and causal
 - (c) Causal but unstable
 - (d) Unstable and not causal
29. The Fourier transform of a conjugate symmetric function is always
 - (a) Imaginary
 - (b) Conjugate anti-symmetric
 - (c) Real
 - (d) Conjugate symmetric
30. The power in the signal $s(t) = 8 \cos[20\pi t - (p/2)] + 4 \sin(15\pi t)$ is
 - (a) 40
 - (b) 41
 - (c) 42
 - (d) 82
31. The unit impulse response of a system is $h(t) = e^{-t}, t \geq 0$
 For this system, the steady-state value of the output for unit step input is equal to
 - (a) -1
 - (b) 0
 - (c) 1
 - (d) ∞
32. A Hilbert transformer is a
 - (a) Non-linear system
 - (b) Non-causal system
 - (c) Time-varying system
 - (d) Low-pass system
33. A real function $f(t)$ has a Fourier transform $F(\omega)$. The Fourier transform of $[f(t) - f(-t)]$ is
 - (a) Zero
 - (b) Real
 - (c) Real and odd
 - (d) Imaginary
34. Identify the transfer function corresponding to an all-pass filter from the following:
 - (a) $\frac{1-s\tau}{1+s\tau}$
 - (b) $\frac{1+s\tau_1}{1+s\tau_2}$
 - (c) $\frac{1}{1+s\tau}$
 - (d) $\frac{s\tau}{1+s\tau}$
35. The rms value of the resultant current in a wire which carries a dc current of 10 A and a sinusoidal alternating current of peak value 20 A is
 - (a) 14.1 A
 - (b) 17.3 A
 - (c) 22.4 A
 - (d) 30.0 A

36. The Laplace transform of a function $f(t)$ if $F(s) = \frac{5s^2 + 23s + 6}{s(s^2 + 2s + 2)}$. As $t \rightarrow \infty$, $f(t)$ approaches
- (a) 3 (b) 5
(c) $\frac{17}{2}$ (d) ∞
37. Which of the following is true?
- (a) A finite signal is always bounded
(b) A bounded signal is always possesses infinite energy
(c) A bounded signal is always zero outside the interval $[-t_0, t_0]$ for some t_0
(d) A bounded signal always finite
38. $x(t)$ is a real valued function of a real variable with period T . Its trigonometric Fourier Series expansion contains no terms of frequency $\omega = 2\pi(2K)/T$; $K = 1, 2, \dots$. Also, no sine terms are present. Then $x(t)$ satisfies the equation
- (a) $x(t) = -x(t - T)$
(b) $x(t) = x(T - t) = -x(-t)$
(c) $x(t) = x(T - t) = -x(t - T/2)$
(d) $x(t) = x(t - T) = x(t - T/2)$
39. A continuous-time system is described by $y(t) = e^{-|x(t)|}$, where $y(t)$ is the output and $x(t)$ is the input. $y(t)$ is bounded
- (a) only when $x(t)$ is bounded
(b) only when $x(t)$ is non-negative
(c) only for $t \geq 0$ if $x(t)$ is bounded $t \geq 0$
(d) even when $x(t)$ is not bounded
40. The running integrator, given by $y(t) = \int_{-\infty}^t x(t') dt'$
- (a) has no finite singularities in its double sided Laplace Transform $Y(s)$
(b) produces a bounded output for every causal bounded input
(c) produces a bounded output for every anticausal bounded input
(d) has no finite zeroes in its double sided Laplace Transform $Y(s)$

LEVEL 2

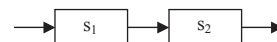
1. If the step response of a causal, linear time-invariant system is $a(t)$, then the response of the system to a general input $x(t)$ would be
- (a) $\int_{0+}^t \frac{da(\tau)}{d\tau} x(t) x(t - \tau) d\tau$
(b) $a(0)x(t) + \int_{0+}^t \frac{da(\tau)}{d\tau} x(t)x(t - \tau) d\tau$
(c) $x(0)a(t) + \int_{0+}^t x(\tau)a(t - \tau) d\tau$
(d) $x(0)a(t) + \int_{0+}^t \frac{da(\tau)}{d\tau} x(t - \tau) d\tau$

2. Two linear time-invariant discrete time system s_1 and s_2 consider the compound system shown in the below figure. Its output is equal to input with a delay of two units. If the transfer function of the first system is given by $H_1(z) = z - 0.5/z - 0.8$, then the transfer function of the second system would be



- (a) $H_2(x) = \frac{z^{-2} - 0.2z^{-3}}{1 - 0.4z^{-1}}$
(b) $H_2(x) = \frac{z^{-2} - 0.8z^{-3}}{1 - 0.5z^{-1}}$
(c) $H_2(x) = \frac{z^{-1} - 0.2z^{-3}}{1 - 0.4z^{-1}}$
(d) $H_2(x) = \frac{z^{-2} - 0.8z^{-3}}{1 - 0.5z^{-1}}$
3. A linear system has the transfer function $H(j\omega) = 1/(j\omega + 1)$. When it is subjected to an input white noise process with a constant spectral density 'A', the spectral density of the output will be
- (a) $\frac{A}{(j\omega + 1)}$ (b) $\frac{A}{(j\omega + 1)^2}$
(c) $\frac{A}{(\omega^2 + 1)}$ (d) $\frac{A}{\sqrt{(\omega^2 + 1)}}$
4. The Fourier series representation of a periodic current is $(2 + 6\sqrt{2} \cos \omega t + \sqrt{48} \sin 2\omega t) A$. The effective value of the current is
- (a) $(2 + 6 + \sqrt{24}) A$ (b) 84
(c) 6 A (d) 2 A
5. A voltage signal $v(t)$ has the following Fourier transform
- $$V(j\omega) = \begin{cases} e^{-j\omega d} & \text{for } |\omega| < 1 \\ 0 & \text{for } |\omega| > 1 \end{cases}$$
- The energy that would be dissipated in a 1Ω resistor fed from $v(t)$ is
- (a) $2/\pi$ Joules (b) $2e^{-2d}$ Joules
(c) $1/\pi$ Joules (d) $1/2\pi$ Joules
6. The output of a linear system to a unit $u(t)$ is $t^2 e^{-2t}$. The system function $H(s)$ is
- (a) $\frac{2}{s^2(s+2)}$ (b) $\frac{2}{(s+2)^2}$
(c) $\frac{2}{(s+2)^3}$ (d) $\frac{2s}{(s+2)^3}$

7. Two linear time-invariant discrete time system s_1 and s_2 are cascaded as shown in the figure. Each system is modelled by a second order difference equation. The difference equation of the overall cascaded system can be of the order



- (a) 0, 1, 2, 3 or 4 (b) either 2 or 4
(c) 2 (d) 4

8. A continuous-time system is governed by the equation $3y^3(t) + 2y^2(t) + y(t) = x^2(t) + x(t)$
 $\{y(t) \text{ and } x(t) \text{ respectively are output and input}\}$. The system is
 (a) Linear and dynamic
 (b) Linear and non-dynamic
 (c) Non-linear and dynamic
 (d) Non-linear and non-dynamic
9. Which one of the following systems is a causal system? [$y(t)$ is output and $u(t)$ is a input step function]
 (a) $y(t) = \sin(u(t+3))$
 (b) $y(t) = 5u(t) + 3u(t-1)$
 (c) $y(t) = 5u(t) + 3u(t+1)$
 (d) $y(t) = \sin(u(t+3)) + \sin(u(t+3))$
10. Which one of the following is the response $y(t)$ of a causal LTI system described by
- $$H(s) = \frac{s+1}{s^2+2s+2}$$
- for given input $x(t) = e^{-t} u(t)$
 (a) $y(t) = e^{-t} \sin tu(t)$
 (b) $y(t) = e^{-(t-1)} \sin(t-1)u(t-1)$
 (c) $y(t) = \sin(t-1)u(t-1)$
 (d) $y(t) = e^{-t} \cos tu(t)$
11. The poles of a digital filter with linear phase response can lie
 (a) Only at $z = 0$
 (b) Only on the unit circle
 (c) Only inside the unit circle but not at $z = 0$
 (d) On the left side of Real $z = 0$ line
12. If $y(t) + \int_0^\infty y(\tau) x(t-\tau) d\tau = \delta(t) + x(t) + x(t)$, then $y(t)$ is
 (a) $u(t)$
 (b) $\delta(t)$
 (c) $r(t)$
 (d) 1
13. The impulse response of a system is $h(t) = \delta(t-0.5)$. If two such systems are cascaded, the impulse response of the overall system will be
 (a) $0.5 \delta(t-0.25)$
 (b) $\delta(t-0.5)$
 (c) $\delta(t-1)$
 (d) $0.5 \delta(t-1)$
14. The minimum number of delay elements required in realizing a digital filter with the transfer function
- $$H(z) = \frac{1+az^{-1}+bz^{-2}}{1+cz^{-1}+dz^{-2}+ez^{-3}}$$
- is
 (a) 2
 (b) 3
 (c) 4
 (d) 5
15. A signal $x(t) = 6 \cos 10\pi t$ is sampled at the rate of 14 Hz. To recover the original signal, the cut off frequency f_c of the ideal low pass filter should be
 (a) $5 \text{ Hz} < f_c < 9 \text{ Hz}$
 (b) 9 Hz
 (c) 10 Hz
 (d) 14 Hz
16. For the system dynamics described by differential equation $y'' + 3y' + 2y = u(t)$, the transfer function of the system represented

controllable canonical form is $C(sI - A)^{-1}B$. The matrix A would be

- (a) $\begin{pmatrix} 0 & 1 \\ -3 & -2 \end{pmatrix}$
 (b) $\begin{pmatrix} 0 & 1 \\ 2 & 3 \end{pmatrix}$
 (c) $\begin{pmatrix} 0 & 1 \\ -2 & -3 \end{pmatrix}$
 (d) $\begin{pmatrix} 0 & 1 \\ 0 & 3 \end{pmatrix}$
17. If $x_1(t) = 2 \sin \pi t + \sin 4\pi t$ and $x_2(t) = \sin 5\pi t + 3 \sin 13\pi t$ then
 (a) x_1 and x_2 both are periodic
 (b) x_1 and x_2 both are not periodic
 (c) x_1 is periodic, but x_2 is not periodic
 (d) x_1 is not periodic, but x_2 is periodic
18. The Fourier transform of a double sided exponential signal $x(t) = e^{-b|t|}$
 (a) Is $\frac{2b}{b^2 + \omega^2}$
 (b) Is $\frac{e^{-j \tan^{-1}(\omega/b)}}{b^2 + \omega^2}$
 (c) Does not exist
 (d) Exists only when it is single sided
19. The Fourier transform of $u(t)$ is
 (a) $\frac{1}{j\omega}$
 (b) $j\omega$
 (c) $\frac{1}{1+j\omega}$
 (d) $\pi \delta(\omega) + \frac{1}{j\omega}$
20. The signal $x(t) = A \cos(\omega_o t + \phi)$ is
 (a) An energy signal
 (b) A power signal
 (c) An energy as well as a power signal
 (d) Neither an energy nor a power signal
21. Which one of the following digital filters have a linear phase response?
 (a) $y(n) + y(n-1) = x(n) - x(n-1)$
 (b) $y(n) = \frac{1}{6} [3x(n) + 2x(n-1) + x(n-2)]$
 (c) $y(n) = \frac{1}{6} [x(n) + 2x(n-1) + 3x(n-2)]$
 (d) $y(n) = \frac{1}{4} [x(n) + 2x(n-1) + x(n-2)]$
22. The Fourier transform $X(f)$ of the periodic delta function $x(t) = \sum_{K=-\infty}^{\infty} \delta(t-KT)$ is
 (a) $T \sum_{K=-\infty}^{\infty} \delta(f-KT)$
 (b) $T \sum_{K=-\infty}^{\infty} \delta\left(f - \frac{K}{T}\right)$
 (c) $\frac{1}{T} \sum_{K=-\infty}^{\infty} \delta\left(f - \frac{K}{T}\right)$
 (d) $\frac{1}{T} \sum_{K=-\infty}^{\infty} \delta(f-KT)$

23. The poles of an analog system are related to the corresponding poles of the digital system by the relation $Z = e^{sT}$. Consider the following statements:

1. Analog system poles in the left half plane map on to digital system poles inside the circle $|Z| = 1$
2. Analog system poles on the imaginary axis of S-plane map on to digital system poles on the unit circle $|Z| = 1$
3. Analog system poles on the imaginary axis of S-plane map on to digital system poles on the circle $|Z| = 1$
4. Analog system poles on the imaginary axis of S-plane map on to digital system zero on the unit circle $|Z| = 1$

Which of these statements are correct?

- (a) 1 and 2 (b) 1 and 3
(c) 3 and 4 (d) 2 and 4

24. The response of a linear, time-invariant, discrete-time system to a unit step input $u(n)$ is the unit impulse $\delta(n)$. The system response to a ramp input $n u(n)$ would be

- (a) $u(n)$ (b) $u(n-1)$
(c) $n \delta(n)$ (d) $\sum_{k=0}^{\infty} k \delta(n-k)$

25. If $X(z) = \frac{z+z^{-3}}{z+z^{-1}}$ then $x(n)$ series has

- (a) Alternate 0s (b) alternate 1s
(c) Alternate 2s (d) alternate -1s

26. A system can be represented in the form of state equation as

$$\begin{aligned} S(n+1) &= A S(n) + B x(n) \\ y(n) &= C S(n) + D x(n) \end{aligned}$$

where, A , B , C and D are matrices, $S(n)$ is the state vector, $x(n)$ is the input and $y(n)$ is the output. The transfer function of the system $H(z) = (Y(z)/X(z))$ is given by

- (a) $A(ZI - B)^{-1} C + D$
(b) $B(ZI - C)^{-1} D + A$
(c) $C(ZI - A)^{-1} B + D$
(d) $A(ZI - A)^{-1} C + B$

27. Two independent signals X and Y known to the Gaussian with mean values x_0 and y_0 and variances σ_x^2 and σ_y^2 . A signal $Z = X - Y$ is obtained from them. The mean z_0 variance σ_z^2 and p. d. f. $p(z)$ of the signal Z are given by

- (a) $x_0 - y_0$, $\sigma_x^2 - \sigma_y^2$, Gaussian
(b) $x_0 + y_0$, $\sigma_x^2 + \sigma_y^2$, Raleigh
(c) $y_0 - x_0$, $\sigma_y^2 - \sigma_x^2$, uniform
(d) $x_0 - y_0$, $\sigma_x^2 + \sigma_y^2$, Gaussian

28. If the cumulative distribution function is $F_x(x)$, then the probability density function $f_x(x)$ is given as

- (a) $\int F_x(x) dx$ (b) $\left(\frac{d}{dx}\right) F_x(x)$
(c) $\int F_x(-x) dx$ (d) $\left(\frac{d}{dx}\right) F_x(-x)$

29. The Fourier transform of $e^{-\pi t^2}$ is $e^{-\pi f^2}$; then the Fourier transform of $e^{-\alpha t^2}$ is

- (a) $\left(\frac{1}{\alpha}\right) \cdot e^{-\alpha f^2}$ (b) $\sqrt{\frac{\pi}{\alpha}} e^{-\frac{\pi^2 f^2}{\alpha}}$
(c) $\frac{1}{\sqrt{\pi \alpha}} e^{-\alpha \pi^2 f^2}$ (d) $\sqrt{\pi \alpha} e^{-\frac{f^2}{\pi^2 \alpha}}$

30. The average value of the full wave rectified sine wave with period p , and a peak value of V_m is

- (a) $0.707 V_m$ (b) $0.505 V_m$
(c) $0.637 V_m$ (d) $0.318 V_m$

31. $y[n] = \sum_{k=-\infty}^n x[k]$

Which one of the following systems is the inverse of the system given above?

- (a) $x(n) = y(n) - y(n-1)$
(b) $x(n) = y(n)$
(c) $x(n) = y(n+4)$
(d) $x(n) = ny(n)$

32. What is the phase angle of the composite sinusoidal signal resulting from the addition of $v_1(n) = \sin(5\pi n)$ and $v_2(n) = \sqrt{2} \cos(5\pi n)$?

- (a) $+5\pi$ (b) -5π
(c) $+\pi$ (d) $-\pi/3$

33. To which one of the following difference equations, the impulse response $h(n) = \delta(n+2) - \delta(n-2)$ corresponds?

- (a) $y(n+2) = x(n) - x(n-2)$
(b) $y(n-2) = x(n) - x(n-4)$
(c) $y(n) = x(n+2) + x(n-2)$
(d) $y(n) = -x(n+2) + x(n-2)$

34. Laplace transforms of $f(t)$ and $g(t)$ are $F(s)$ and $G(s)$, respectively. Which one of the following expressions gives the inverse Laplace transform of $F(s) G(s)$?

- (a) $f(t)g(t)$ (b) $\frac{f(t)}{g(t)}$
(c) $f(t) + g(t)$ (d) $f(t) * g(t)$

35. The impulse response of a linear time invariant system is a rectangular pulse of duration T . It is excited by an input of a pulse of duration T . What is the filter output waveform?

- (a) Rectangular pulse of duration T
(b) Rectangular pulse of duration $2T$
(c) Triangular pulse of duration T
(d) Triangular pulse of duration $2T$

36. Consider the following systems:

- (1) $Y[k] = x[k] + \alpha_1 x[k-1] - b_1 y[k-1] - b_2 y[k-2]$
(2) $Y[k] = x[k] + \alpha_1 x[k-1] + a_2 x[k-2]$
(3) $Y[k] = x[k+1] + \alpha_1 x[k] + \alpha_2 x[k-1]$
(4) $Y[k] = \alpha_1 x[k] + \alpha_2 x[k+1] - b_1 y[k-2]$

Which of the systems given above represent recursive discrete system?

- (a) 1 and 4 (b) 1 and 2
(c) 1, 2 and 3 (d) 2, 3 and 4

37. A linear constant parameter continuous time system has the following A matrix in its state representation $\dot{X} = AX + Bu$

$$A = \begin{bmatrix} 0 & \alpha \\ \alpha & 0 \end{bmatrix}$$

Which one of the following is the natural response of the system following the application of any input?

- (a) $M e^{\alpha t} N e^{-\alpha t}$ (b) $(M + Nt)e^{\alpha t}$
(c) $(M + Nt)e^{-\alpha t}$ (d) $M \cos \alpha t + N \sin \alpha t$

38. For half wave (odd) symmetry, with T_0 = period of $x(t)$, which one of the following is true?

- (a) $x\left(t \pm \frac{T_0}{2}\right) = -x(t)$ (b) $x\left(t \pm \frac{T_0}{2}\right) = x(t)$
(c) $x(t \pm T_0) = -x(t)$ (d) $x(t \pm T_0) = x(t)$

39. A square wave is defined by

$$x(t) = \begin{cases} A & ; 0 < t < \frac{T_0}{2} \\ -A & ; \frac{T_0}{2} < t < T_0 \end{cases}$$

It is periodically extended outside this interval. What is the general coefficient α_n in the Fourier expansion of this wave?

- (a) 0 (b) $\frac{2A(1 - \cos n\pi)}{(n\pi)}$
(c) $\frac{2A(1 + \cos n\pi)}{(n\pi)}$ (d) $\frac{2A(1 - \cos n\pi)}{(n+1)\pi}$

40. What is the inverse Laplace transform of e^{-as}/s ?

- (a) e^{-at} (b) $u(t-a)$
(c) $\delta(t-a)$ (d) $(t-a)u(t-a)$

41. Given that $x_1(t) = e^{k_1 t} u(t)$ and $x_2(t) = e^{k_2 t} u(t)$. Which one of the following gives their convolution?

- (a) $\frac{e^{K_1 t} - e^{K_2 t} u(t)}{K_1 + K_2}$ (b) $\frac{e^{K_1 t} - e^{K_2 t} u(t)}{K_2 + K_1}$
(c) $\frac{e^{K_1 t} + e^{-K_2 t} u(t)}{K_1 + K_2}$ (d) $\frac{e^{K_1 t} + e^{-K_2 t} u(t)}{K_2 - K_1}$

42. Which one of the following must be satisfied if a signal is to be periodic for $-\infty < t < \infty$?

- (a) $x(t+T_0) = x(t)$ (b) $x(t+T_0) = \frac{dx(t)}{dt}$
(c) $x(t+T_0) = \int_t^{T_0} x(t) dt$ (d) $x(t+T_0) = x(t) + KT_0$

43. What is the output of the system with $h(n) = (1/2)^n u(n)$ in response to the input $x(n) = 3 + \cos(\pi n + (\pi/3))$?

- (a) $y(n) = 3 + \frac{1}{3} \left(\cos\left(\pi n + \frac{\pi}{3}\right) \right)$
(b) $y(n) = 3 + \frac{2}{3} \left(\cos\left(\pi n + \frac{\pi}{3}\right) \right)$
(c) $y(n) = 1 + \frac{2}{3} \left(\sin\left(\pi n + \frac{\pi}{3}\right) \right)$
(d) $y(n) = 6 + \frac{2}{3} \left(\cos\left(\pi n + \frac{\pi}{3}\right) \right)$

44. A discrete time system has impulse response $h(n) = a^n u(n+2)$, $|a| < 1$. Which one of the following statements is correct?

The system is

- (a) Stable, casual and memory less
(b) Unstable, casual and has memory
(c) Stable, non-casual and has memory
(d) Unstable, non-casual and memory less

45. What is the number of roots of the polynomial $F(z) = 4z^3 - 8z^2 - z + 2$ lying outside the unit circle?

- (a) 0 (b) 1
(c) 2 (d) 3

46. Which one of the following gives the cross-correlation $Y_{xy}(K)$ of two finite length sequence $x(n) = \{1, 3, 1, 2\}$ and $y(n) = \{1, 2, 1, 3\}$?

- (a) $\{3, 10, 8, 14, 7, 5, 2\}$
(b) $\{2, 10, 7, 14, 6, 6, 3\}$
(c) $\{3, 9, 8, 14, 7, 5, 2\}$
(d) $\{2, 10, 6, 14, 7, 5, 3\}$

47. Which one of the following given the average value or expectation of the function $g(X)$ of the random variable X ? (Given $f(X)$ is the probability density function)

- (a) $E(g(X)) = \int_{-\infty}^{\infty} g(X) dX$
(b) $E(g(X)) = \int_{-\infty}^{\infty} g(X) f(X) dX$
(c) $E(g(X)) = \int_{-\infty}^{\infty} g^*(X) dX$
(d) $E(g(X)) = \int_{-\infty}^{\infty} \frac{g(X)}{f(X)} dX$

48. A signal $V(n)$ is defined by

$$V[n] = \begin{cases} 1 & ; n = 1 \\ -1 & ; n = -1 \\ 0 & ; n = 0 \text{ and } |n| > 1 \end{cases}$$

What is the value of the composite signal defined as $V(n) + V(-n)$?

- (a) 0 for all integer values of n
- (b) 2 for all integer values of n
- (c) 1 for all integer values of n
- (d) -1 for all integer values of n

49. The lengths of two discrete time sequences $x_1(n)$ and $x_2(n)$ are 5 and 7, respectively. What is the maximum length of a sequence $x_1(n) * x_2(n)$?

- (a) 5
- (b) 6
- (c) 7
- (d) 11

50. The unit sample response of a discrete system is 1 (1/2) (1/4) 0 0 0 For and input sequence 101000.... What is the output sequence?

- (a) 1 1/2 1/4 1/2 1/4 0 0.....
- (b) 1 0 1/4 0 0 0
- (c) 2 1/2 5/4 0 0
- (d) 1 1/2 5/4 1/2 1/4 0 0.....

51. Let $x[n] = a^n u[n]$; $h[n] = b^n u[n]$

What is the expression for $y[n]$, for a discrete-time system?

- (a) $\sum_{K=-\infty}^{\infty} a^k u[k] b^{n-k} u[n-k]$
- (b) $\sum_{K=-\infty}^{\infty} a^n u[k] b^{n-k} u[n-k]$
- (c) $\sum_{K=-\infty}^{\infty} a^k u[n-k] b^n u[k]$
- (d) $\sum_{K=-\infty}^{\infty} a^{n-k} u[k] b^{n-k} [n-k]$

52. The output $y[n]$ of a discrete time LTI system is related to the input $x[n]$ as given below:

$$Y(n) = \sum_{K=0}^{\infty} x[k]$$

Which one of the following correctly relates the z -transforms of the input and output, denoted by $X[z]$ and $Y[z]$, respectively?

- (a) $Y(z) = (1 - z^{-1}) X(z)$
- (b) $Y(z) = z^{-1} X(z)$
- (c) $Y(z) = \frac{X(z)}{1 - z}$
- (d) $Y(z) = \frac{dX(z)}{dz}$

53. A signal represented by $x(t) = 5 \cos 400 \pi t$ is sampled at a rate 300 sample/s. The resulting samples are passed through an ideal low pass filter of cut-off frequency 150 Hz. Which of the following will be contained in the output of the LPF?

- (a) 100 Hz
- (b) 100 Hz, 150 Hz
- (c) 50 Hz 100 Hz
- (d) 50 Hz, 100 Hz, 150 Hz

54. Which one of the following is the inverse z -transform of $X(z)$

$$= X(z) = \frac{z}{(z-2)(z-3)} \quad |z| < 2 ?$$

- (a) $[2^n - 3^n] u(-n-1)$
- (b) $[3^n - 2^n] u(-n-1)$
- (c) $[2^n - 3^n] u(-n-1)$
- (d) $[2^n - 3^n] u(n)$

55. The auto correlation function $R_x(\tau)$ of a random process has the property that $R_x(0)$ is equal to

- (a) The square of the mean value of the process
- (b) The mean squared value of the process
- (c) The smallest value of $R_x(t)$
- (d) $\frac{1}{2} [R_x(t) + R_x(-t)]$

56. The discrete time Fourier transform (DTFT) of $x(n) = 2(3)^n u(-n)$ is equal to

- (a) $\frac{2}{1 - e^{j\Omega/3}}$
- (b) $\frac{2}{1 + e^{j\Omega/3}}$
- (c) $2 \left(\frac{1 + e^{j\Omega/3}}{1 - e^{j\Omega/3}} \right)$
- (d) $2 \left(\frac{1 - e^{j\Omega/3}}{1 + e^{j\Omega/3}} \right)$

57. Which one of the following is the correct statement? The system characterized by the equation $y(t) = a x(t) + b$ is

- (a) linear for any value of b
- (b) linear if $b > 0$
- (c) linear if $b < 0$
- (d) non-linear

58. What is the Laplace transform of $x(t) = -e^{2t} u(t) * t u(t)$?

- (a) $\frac{-1}{s^2(s+2)}$
- (b) $\frac{-1}{s^2(s-2)}$
- (c) $\frac{1}{s^2(s-2)}$
- (d) $\frac{-1}{s(s-2)}$

59. What is the inverse z transform of $X(z)$?

- (a) $\frac{1}{2\pi j} \oint X(z) z^{n-1} dz$
- (b) $2\pi j \oint X(z) z^{n+1} dz$
- (c) $\frac{1}{2\pi j} \oint X(z) z^{1-n} dz$
- (d) $2\pi j \oint X(z) z^{-n+1} dz$

60. The impulse response of a system $h(n) = a^n u(n)$. What is the condition for the system to be BIBO stable?

- (a) A is real and positive
- (b) A is real and negative
- (c) $|a| > 1$
- (d) $|a| < 1$

61. Which one of the following is the correct statement? The region of convergence of z transform of $x(n) r^{-n}$ is

- (a) absolutely integrable
- (b) absolutely summable
- (c) unity
- (d) < 1

62. $x[n]$ is defined as

$$x[n] = \begin{cases} 0 & ; \text{ for } n < -2 \text{ or } n > 4 \\ & ; \text{ otherwise} \end{cases}$$

Determine the value of n for which

$X[-n-2]$ is guaranteed to be zero

- (a) $n < 1$ and $n > 7$ (b) $n < -4$ and $n > 2$
(c) $n < -6$ and $n > 0$ (d) $n < -2$ and $n > 4$

63. The discrete-time signal $x[n]$ is given as

$$x[n] = \begin{cases} 1, & n = 1, 2 \\ -1, & n = -1, -2 \\ 0, & n = 0 \text{ and } |n| > 2 \end{cases}$$

Which one of the following is the time-shifted signal $y[n] = x[n+3]$?

(a) $y[n] = \begin{cases} 1, & n = -1, -2 \\ -1, & n = -4, -5 \\ 0, & n = -3, n < -5 \text{ and } n > -1 \end{cases}$

(b) $y[n] = \begin{cases} 0, & n = -1, -2 \\ -1, & n = -4, -5 \\ 1, & n = -3, n < -5 \text{ and } n > -1 \end{cases}$

(c) $y[n] = \begin{cases} 1, & n = -1, -2 \\ 0, & n = -4, -5 \\ -1, & n = -3, n < -5 \text{ and } n > -1 \end{cases}$

(d) $y[n] = \begin{cases} -1, & n = 1, 2 \\ 1, & n = 4, 5 \\ 0, & n = 3, n > 5 \text{ and } n < 1 \end{cases}$

64. If the Fourier transform of $x(t)$ is $\frac{2}{\omega} \sin(\pi\omega)$ then what is the Fourier transform of $e^{j5t} x(t)$?

- (a) $\frac{2}{\omega-5} \sin(\pi\omega)$ (b) $\frac{2}{\omega} \sin\{\pi(\omega-5)\}$
(c) $\frac{2}{\omega+5} \sin\{\pi(\omega+5)\}$ (d) $\frac{2}{\omega-5} \sin\{\pi(\omega-5)\}$

65. What is $F(s) = \frac{8s+10}{(s+1)(s+2)^3}$ equal to?

- (a) $\frac{2}{s+1} + \frac{4}{(s+2)^3} - \frac{4}{(s+2)^2} - \frac{2}{s+2}$
(b) $\frac{2}{s+1} + \frac{6}{(s+2)^3} - \frac{2}{(s+2)^2} - \frac{2}{s+2}$
(c) $\frac{2}{s+1} + \frac{6}{(s+2)^3} - \frac{2}{(s+2)^2} + \frac{2}{s+2}$
(d) $\frac{4}{s+1} + \frac{6}{(s+2)^3} - \frac{2}{(s+2)^2} - \frac{4}{s+2}$

66. For the function $x(t)$, $X(s)$ is given by

$$X(s) = e^{-s} \left[\frac{-2}{s(s+2)} \right]$$

Then, what are the initial and final values of $x(t)$, respectively?

- (a) 0 and 1 (b) 0 and -1
(c) 1 and 1 (d) -1 and 0

67. What is the inverse Fourier transform of $u(\omega)$?

- (a) $\frac{1}{2} \delta(t) + \frac{1}{\pi t}$ (b) $\frac{1}{2} \delta(t)$
(c) $2 \delta(t) + \frac{1}{\pi t}$ (d) $2 \delta(t) + \text{sgn}(t)$

68. Fourier transform $F(j\omega)$ of an arbitrary signal has the property

- (a) $F(j\omega) = F(-j\omega)$ (b) $F(j\omega) = -F(-j\omega)$
(c) $F(j\omega) = F^*(-j\omega)$ (d) $F(j\omega) = -F^*(-j\omega)$

69. The inverse Fourier transform of the function

$$F(j\omega) = (1/j\omega) + \pi\delta(\omega)$$

- (a) $\sin \omega t$ (b) $\cos \omega t$
(c) $\text{sgn}(t)$ (d) $u(t)$

70. The final value of $\text{LT}^{-1} \frac{2s+1}{s^4+8s^3+16s^2+s}$ is

- (a) infinity (b) 2
(c) 1 (d) zero

71. The two inputs to an analogue multiplier are $x(t)$ and $y(t)$ with Fourier transforms $X(f)$ and $Y(f)$ respectively. The output $z(t)$ will have a transform $Z(f)$ given by

- (a) $X(f) \cdot Y(f)$ (b) $X(f) + Y(f)$
(c) $X(f)/Y(f)$ (d) $\int_{-\infty}^{\infty} X(\lambda) Y(f-\lambda) d\lambda$

72. The impulse response of a system is $h(t)$. When the input is $x(t)$, the output $y(t)$ will $[H(f)$ is the Fourier transform of $h(t)]$

- (a) $h(t)x(t)$ (b) $|H(f)|x(t)$
(c) $h(t)x^*(t)$ (d) $h(t)$

73. The current through a resistance $R = 10$ ohms is $i = 2 \cos(\omega t) + \cos(3\omega t) + 5 \cos(5\omega t)$. The average power in the resistance is

- (a) 80 W (b) 150 W
(c) 300 W (d) 640 W

74. The system described by the difference equation $y(n) - 2y(n-1) + y(n-2) = x(n) - x(n-1)$ has $y(n) = 0$ and $n < 0$. If $x(n) = \delta(n)$, then $y(2)$ will be

- (a) 2 (b) 1
(c) zero (d) -1

75. Which one of the following is the correct Fourier transform of the unit step signal?

- (a) $\pi\delta(\omega)$ (b) $1/j\omega$
(c) $1/j\omega + \pi\delta(\omega)$ (d) $1/j\omega + 2\pi\delta(\omega)$

76. If $\delta(t)$ denotes a unit impulse, then the Laplace transform of $[d^2 \delta(t)/dt^2]$ will be

- (a) 1 (b) s^2
(c) s (d) s^{-2}

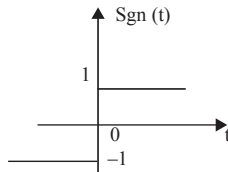
77. Which one of the following represents the impulse response of a system defined by $H(z) = z^{-m}$?

- (a) $u(n-m)$ (b) $\delta(n-m)$
(c) $\delta(m)$ (d) $\delta(m-n)$

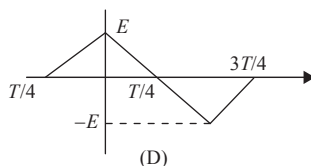
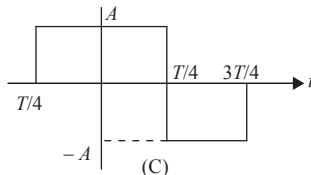
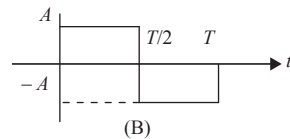
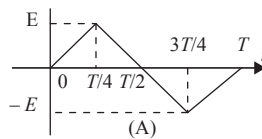
78. A periodic voltage having the Fourier series $v(t) = 1 + 4 \sin \omega t + 2 \cos \omega t$ volts is applied across a one-ohm resistor. The power dissipated in the one-ohm resistor is
 (a) 1 W (b) 11 W
 (c) 21 W (d) 24.5 W
79. Let $F(\omega)$ be the Fourier transform of a function $f(t)$, then $F(0)$ is
 (a) $\int_{-\infty}^{\infty} f(t) dt$ (b) $\int_{-\infty}^{\infty} |f(t)|^2 dt$
 (c) $\int_{-\infty}^{\infty} |tf(t)|^2 dt$ (d) $\int_{-\infty}^{\infty} tf(t) dt$
80. The period of the function $\cos(\pi/4)(t-1)$ is
 (a) $(1/8) \cdot s$ (b) 8s
 (c) 4s (d) $(1/4) s$

LEVEL 3

1. The Fourier transform of the function $\text{Sgn}(t)$ defined in the figure is



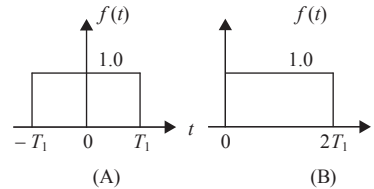
- (a) $-2/j\omega$ (b) $4/j\omega$
 (c) $2/j\omega$ (d) $1/j\omega + 1$
2. Which of the following periodic wave will have only odd harmonics of sinusoidal waveforms?



Select the correct answer using the codes given below:

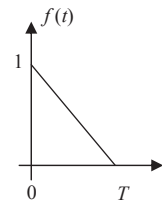
Codes:

- (a) (A) and (B) (b) (A) and (C)
 (d) (A) and (D) (d) (B) and (D)
3. Which one the following in the Fourier transform of the signal given in Figure (B), if the Fourier transform of the signal in Figure (A) is given by $\frac{2 \sin \omega T_1}{\omega}$?



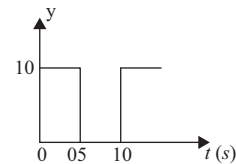
- (a) $\frac{2 \sin \omega T_1}{\omega} e^{+j\omega 2T_1}$ (b) $\frac{2 \sin \omega T_1}{\omega} e^{-j\omega T_1}$
 (c) $\frac{2 \sin \omega T_1}{\omega} e^{-j\omega 2T_1}$ (d) $\frac{2 \sin \omega T_1}{\omega} e^{+j\omega T_1}$

4. Which one of the following is the correct Laplace transform of the signal in the given figure?

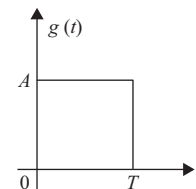


- (a) $\frac{1}{Ts^2} [1 - e^{-Ts} (1 + Ts)]$ (b) $\frac{1}{Ts^2} (e^{-Ts} - 1 + Ts)$
 (c) $\frac{1}{Ts^2} (e^{-Ts} + 1 - Ts)$ (d) $\frac{1}{Ts^2} (1 - e^{-Ts} + Ts)$

5. In the given figure, the effective value of the waveform is



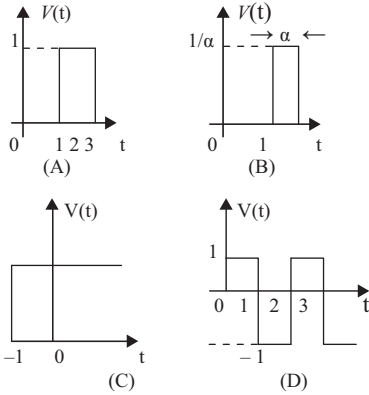
- (a) 5.0 (b) 2.5
 (c) $\sqrt{2.5}$ (d) $\sqrt{50}$
6. The energy density spectrum $G(f)$ of a rectangular pulse shown in the given figure is



- (a) $AT \left(\frac{\sin \pi f T}{\pi f T} \right)$ (b) $(AT)^2 \left(\frac{\sin \pi f T}{\pi f T} \right)^2$
(c) $AT^2 \left(\frac{\sin \pi f T}{\pi f T} \right)$ (d) $A^2 \left(\frac{\sin \pi f T}{\pi f T} \right)$

7. Match List I with List II and select answer using the codes given below the list.

List I



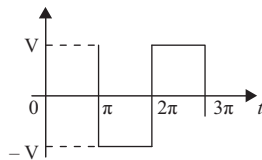
List II

1. $v(t) = u(t+1)$
2. $v(t) = u(t) - 2u(t-1) + 2u(t-2) - 2u(t-3) + \dots$
3. $v(t) = u(t-1) - u(t-3)$
4. $v(t) = \delta(t-1)$

Codes:

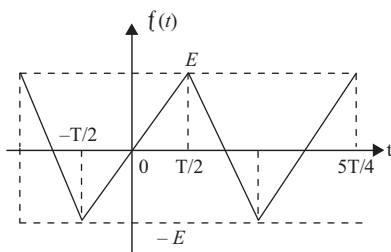
	A	B	C	D
(a)	1	2	3	4
(b)	3	4	1	2
(c)	4	3	2	1
(d)	4	3	1	2

8. The amplitude of the first odd harmonic of the square wave shown in the figure is equal to



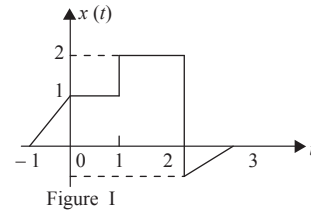
- (a) $4V/\pi$ (b) $2V/3\pi$
(c) V/π (d) 0

9. A periodic triangular wave is shown in the figure. Its Fourier components will consist only of

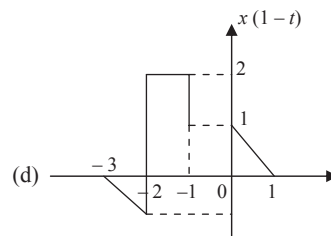
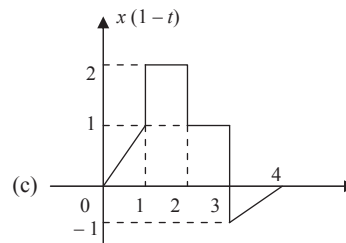
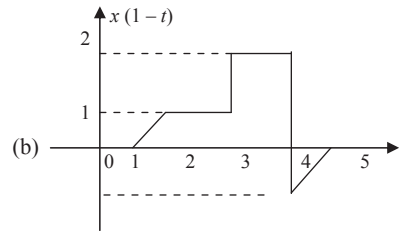
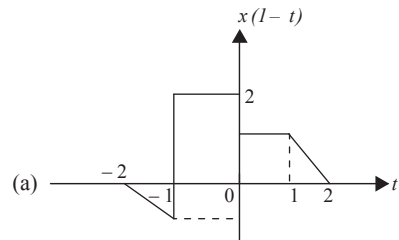


- (a) all cosine terms (b) all sine terms
(c) odd cosine terms (d) odd sine terms

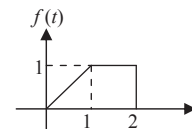
10. If a plot of a signal $x(t)$ is as shown in the figure I



Then the plot of the signal $x(1-t)$ will be

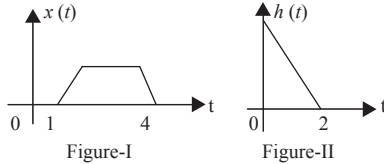


11. The function $f(t)$ shown in the given figure will have Laplace transform as



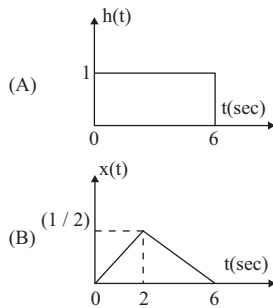
- (a) $\frac{1}{s^2} - \frac{1}{s}e^{-s} - \frac{1}{s^2}e^{-2s}$ (b) $\frac{1}{s^2}(1 - e^{-s} - e^{-2s})$
 (c) $\frac{1}{s}(1 - e^{-s} - e^{-2s})$ (d) $\frac{1}{s^2}(1 - e^{-s} - se^{-2s})$

12. Figure I and Figure II show respectively, the input $x(t)$ to a linear time-invariant system and the impulse response $h(t)$ of the system

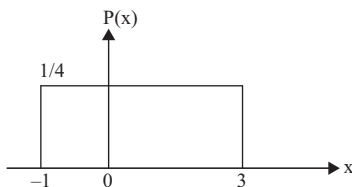


The output of the system is zero everywhere except for the time interval

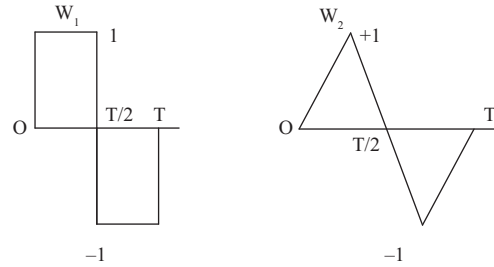
- (a) $0 < t < 4$ (b) $0 < t < 5$
 (c) $1 < t < 5$ (d) $1 < t < 6$
13. The impulse response and the excitation function of a linear time invariant causal system are shown in Figure. A and B respectively. The output of the system at $t = 2$ sec, is equal to



- (a) 0 (b) 1/2
 (c) (3/2) (d) 2
14. For a random variable x following the probability density function, $p(x)$ shown in the figure. The mean and the variance are, respectively

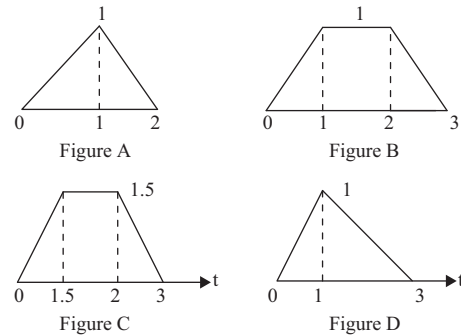


- (a) 1/2 and 2/3 (b) 1 and 4/3
 (c) 1 and 2/3 (d) 4 and 4/3
15. One period $(0, T)$ each of two periodic waveforms W_1 and W_2 are shown in the figure. The magnitudes of the n^{th} Fourier series coefficients of W_1 and W_2 for $n \geq 1$, n odd, are respectively proportional to

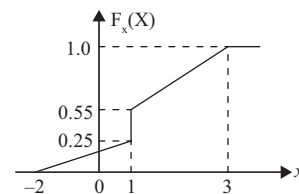


- (a) $|n^{-3}|$ and $|n^{-2}|$ (b) $|n^{-2}|$ and $|n^{-3}|$
 (c) $|n^{-1}|$ and $|n^{-2}|$ (d) $|n^{-4}|$ and $|n^{-2}|$

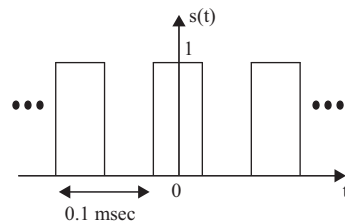
16. Let $u(t)$ be the unit step function. Which of the waveform in the figure (A) – (D) corresponds to the convolution of $u(t) - u(t-1)$ with $u(t) - u(t-2)$?



- (a) Figure-A (b) Figure-B
 (c) Figure-C (d) Figure-D
17. The distribution function $F_X(x)$ of a random variable X is shown in the figure. The probability that $X = 1$ is

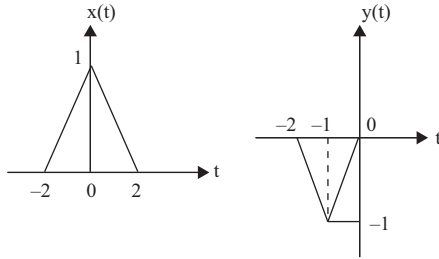


- (a) zero (b) 0.25
 (c) 0.55 (d) 0.33
18. A rectangular pulse train $s(t)$ as shown in the figure is convolved with the signal $\cos^2(4\pi \times 10^3 t)$. The convolved signal will be a



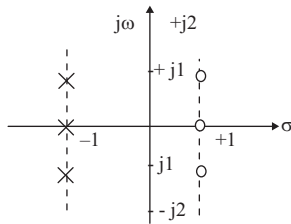
- (a) DC (b) 12 kHz sinusoid
 (c) 8 kHz sinusoid (d) 14 kHz sinusoid

19. Let $x(t)$ and $y(t)$ (With Fourier transforms $X(f)$ and $Y(f)$ respectively) be related as shown in the figure

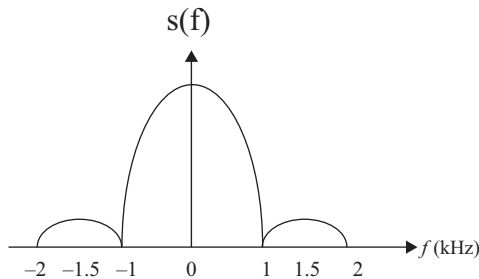


Then $Y(f)$ is

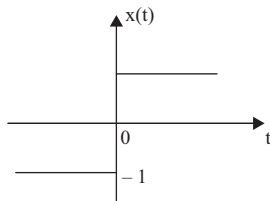
- (a) $-\frac{1}{2} X(f/2) e^{-j2\pi f}$ (b) $-\frac{1}{2} X(f/2) e^{j2\pi f}$
(c) $-X[1/2] e^{j2\pi f}$ (d) $-X(f/2) e^{-j2\pi f}$
20. The pole-zero pattern of a certain filter is shown in the figure below. The filter must be which of the following type?



- (a) low-pass (b) high-pass
(c) all-pass (d) band-pass
21. A deterministic signal has the power spectrum given in the figure. The minimum sampling rate needed to completely represent this signal is

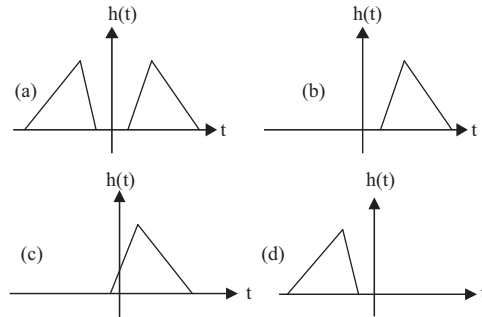


- (a) 1 kHz (b) 2 kHz
(c) 3 kHz (d) none of the above
22. The function $x(t)$ is shown in the figure. Even and odd parts of a unit-step function $u(t)$ are respectively

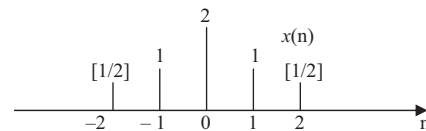


- (a) $\frac{1}{2}, \frac{1}{2}x(t)$ (b) $-\frac{1}{2}, \frac{1}{2}x(t)$
(c) $\frac{1}{2}, -\frac{1}{2}x(t)$ (d) $-\frac{1}{2}, -\frac{1}{2}x(t)$

23. Which of the following can be impulse response of a causal system?



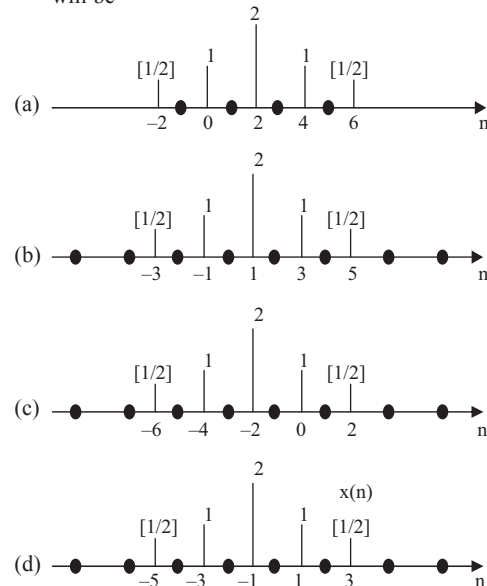
24. A sequence $x(n]$ has non-zero values as shown in the figure



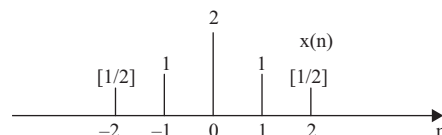
The sequence

$$y(n) = \begin{cases} x[(n/2) - 1] & \text{for } n \text{ even} \\ 0 & \text{for } n \text{ odd} \end{cases}$$

will be



25. A sequence $x(n]$ has non-zero values as shown in the figure



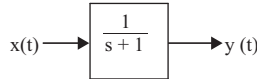
The sequence

$$y(n) = x[(n/2)-1] \quad ; \quad \text{for } n \text{ even} \\ = 0 \quad ; \quad \text{for } n \text{ odd}$$

The Fourier transform of $y(2n)$ will be

- (a) $e^{-j2\omega} [\cos 4\omega + 2 \cos 2\omega + 2]$
 (b) $\cos 2\omega + 2 \cos \omega + 2$
 (c) $e^{-j\omega} [\cos 2\omega + 2 \cos \omega + 2]$
 (d) $e^{-j2\omega} [\cos 2\omega + 2 \cos 2\omega + 2]$

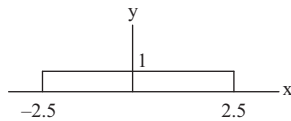
26. In the system shown below, $x(t) = (\sin t) u(t)$. In steady state, the response $y(t)$ will be



- (a) $(1/\sqrt{2}) \sin [t - (\pi/4)]$
 (b) $(1/\sqrt{2}) \sin [t + (\pi/4)]$
 (c) $(1/\sqrt{2}) e^{-1} \sin t$
 (d) $\sin t - \cos t$
27. A uniformly distributed random variable X with probability density function

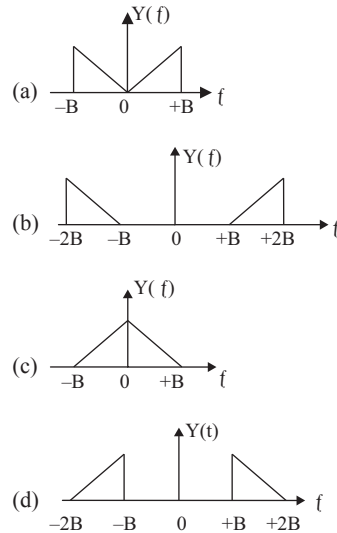
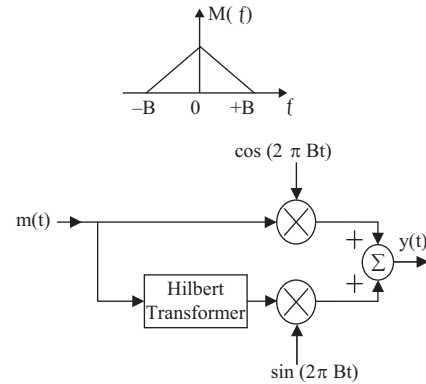
$$f_x(x) = [1/10] [u(x+5) - u(x-5)]$$

Where, $u(\cdot)$ is the unit step function is passed through a transformation given in the figure below. The probability density function of the transformed random variable Y would be



- (a) $f_y(y) = [1/5] [u(y+2.5) - u(y-2.5)]$
 (b) $f_y(y) = 0.5\delta(y) + 0.5\delta[y-1]$
 (c) $f_y(y) = 0.25\delta(y+2.5) + 0.25\delta(y-2.5) + 0.5\delta(y)$
 (d) $f_y(y) = 0.25\delta(y+2.5) + 0.25\delta(y-2.5) + (1/10)[u(y+2.5) - u(y-2.5)]$

28. In the following scheme, if the spectrum $M(f)$ of $m(t)$ is as shown, then the spectrum $Y(f)$ of $y(t)$ will be



ANSWER KEYS

LEVEL 1

1. (b)	2. (c)	3. (c)	4. (b)	5. (a)	6. (d)	7. (d)	8. (a)	9. (b)	10. (b)
11. (d)	12. (b)	13. (b)	14. (d)	15. (c)	16. (c)	17. (b)	18. (a)	19. (d)	20. (c)
21. (c)	22. (d)	23. (d)	24. (a)	25. (b)	26. (b)	27. (b)	28. (a)	29. (c)	30. (a)
31. (b)	32. (a)	33. (d)	34. (a)	35. (b)	36. (a)	37. (c)	38. (d)	39. (d)	40. (b)

LEVEL 2

1. (a)	2. (b)	3. (c)	4. (b)	5. (c)	6. (c)	7. (d)	8. (d)	9. (b)	10. (a)
11. (a)	12. (b)	13. (c)	14. (b)	15. (a)	16. (c)	17. (a)	18. (a)	19. (d)	20. (b)
21. (a)	22. (c)	23. (b)	24. (a)	25. (d)	26. (c)	27. (a)	28. (b)	29. (b)	30. (d)
31. (a)	32. (d)	33. (b)	34. (d)	35. (d)	36. (a)	37. (a)	38. (a)	39. (b)	40. (b)
41. (a)	42. (a)	43. (d)	44. (c)	45. (b)	46. (a)	47. (b)	48. (a)	49. (d)	50. (d)
51. (a)	52. (c)	53. (a)	54. (a)	55. (b)	56. (a)	57. (d)	58. (b)	59. (a)	60. (d)
61. (b)	62. (c)	63. (a)	64. (d)	65. (b)	66. (b)	67. (a)	68. (c)	69. (d)	70. (c)
71. (d)	72. (c)	73. (c)	74. (c)	75. (c)	76. (b)	77. (b)	78. (c)	79. (a)	80. (b)

LEVEL 3

1. (c)	2. (a, b)	3. (b)	4. (b)	5. (a)	6. (c)	7. (a)	8. (b)	9. (c)	10. (b)
11. (d)	12. (c)	13. (b)	14. (b)	15. (c)	16. (b)	17. (b)	18. (d)	19. (b)	20. (c)
21. (d)	22. (c)	23. (b)	24. (a)	25. (c)	26. (a)	27. (b)	28. (a)		

4

CHAPTER

NETWORK THEORY

4.1 NETWORK GRAPHS: MATRICES ASSOCIATED WITH GRAPHS; INCIDENCE, FUNDAMENTAL CUT SET AND FUNDAMENTAL CIRCUIT MATRICES

Network to Pology

This is concerning the manner in which various elements in network are grouped and inter connected at their terminals irrespective of their value and type.

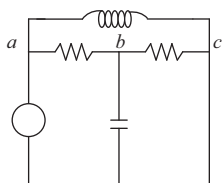


Fig. 4.1 Network

Graph of Network

The diagram that gives network configuration and uses with very small circle at the graph of network.

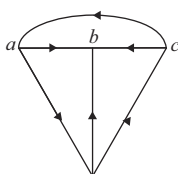


Fig. 4.2 Network oriented graph

Oriented Graph

If the reference directions are shown by an arrow for each line then it is called the oriented graph.

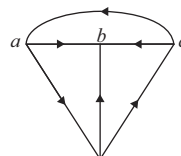


Fig. 4.3 Network oriented graph

Tree of Graph

Any connected open set of branches, which includes all the nodes of the graph is called the tree. A tree does not contain any closed path.

The branches which are removed from the graph in forming a tree, are called **link or chords (dotted line)**.

The branches which are connected in a tree, are called **Branches or twig (solid line)**.

Properties of Tree

1. It contains all the nodes of the graph.
2. If a graph contains n nodes then its tree will have $(n - 1)$ branches.
3. There is no closed path and hence a tree is circuitless.
Number of branches in tree = number of KCL equation = $(n - 1)$.
Number of links or chords = number of KVL equation = $b - (n - 1) = b - n + 1$.

Co-Tree

Remaining part of a graph after removal of twigs is called co-tree. It is a collection of twigs.

Topology deals with the properties of network which are unaffected when we stretch, twist or otherwise distort the size and shape of the network. For example, by shortening or lengthening the connecting wire between elements.

Topological properties of network are well understood by repairmen who compares the schematic diagram for radio or TV set with actual wiring in the chesis.

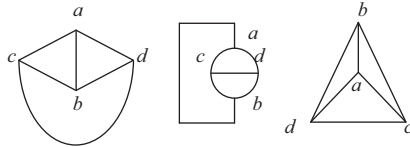


Fig. 4.4

Some topological structure have special name

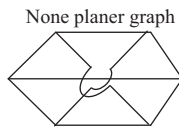
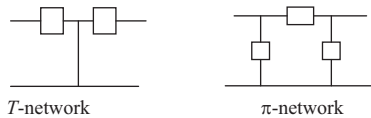


Fig. 4.5

Tie Set Matrix/(Fundamental Loop) (KVL)

A tie set is a set of branches contained in a loop such that each loop contains one link or chord and remainder are Tree branches.

We can use this matrix to write the branch current in terms of the loop current flowing through the link.

Cut Set Matrix/(Fundamental Node) (KCL)

Each cut set contains one tree branch, the remaining elements are the tree link.

This matrix provides a method for the selection of representing branch voltage in term of node voltage.

Equilibrium Equation

These are a set of equations that completely and uniquely determine the state of network at any moments.

The equilibrium equation for a given network can be formulated using two different techniques:

1. Through a set of voltage law equation in which the current is independent variable. This method is called formulation

of equilibrium equation on loop basis. This is also called the tie set schedule. Here the number of equations required will be $b - n + 1$.

2. Through a set of current law equation in which the node pair voltage are independent variable. This is called formulation of equilibrium equation on node basis. This is also called cut set schedule. Here the number of equations will be $n - 1$.

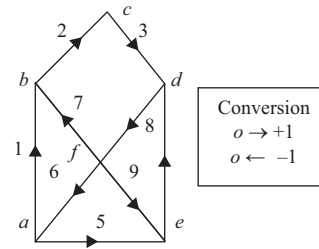


Fig. 4.6

1. Number of fundamental tie set – number of links in tree.
2. Each fundamental tie set will contain only one link and all other will be twig or branches.
3. Direction of fundamental tie set will be same as that of link.

Fundamental Node/Cut Set Matrix (Q_f)

1. Number of cut set = Number of twig branches in the tree.
2. Each fundamental cut set will contain only one twig and other will be link.
3. Direction of f -cut is same as direction of twigs towards node as reference node.
4. Each cut set will be around each node with one node as reference node.

Graph Theory

The diagram that gives the network geometry and use lines with dots at the ends to represent network element is called a graph's of the given network.

Tree of Network

- The residual, after removal of branches to disallow a closed path is called a tree.
- $n = n_t - 1$
where, n = is the number of tree branches.
 n_t = total number of node.
- Remaining branches are called "link".
- $b = l + n$
where,
 b = total number of branches in the graph.
 l = number of links.

Fundamental Loop Matrix

A fundamental loop of a graph G with respect to a tree T is a loop that is made up of one chord and a unique set of branches of T .

Procedure for Deriving FLM is

- Draw the graph of network and choose a tree T assigning arbitrary orientation to all branches of the graph.
- Designate the fundamental loops corresponding to T and assign arbitrary orientation to them.
- Apply KVL to each fundamental loop and put the resulting equation in matrix form.

$$B_f V_b = 0$$

$$V_b = (V_1 \ V_2 \ \dots \ V_B)^T$$

Relationship of Matrices

- $AB_f^T = 0$ and $B_f Q_f^T = 0$
where, A is the incidence matrix.
 B_f fundamental loop matrix.
 Q_f fundamental cut set matrix.
- Rank of incidence matrix is N , i.e., among $(N+1)$ equation, only N equation are linearly independent and any one of the $N+1$ equation can be deleted.
- Deleted row is called reference or datum node.
- For any lumped electrical network the algebraic sum of the current entering a cut set is equal to zero.

$$Q_a i_b = 0$$

where, Q_a = augmented cut set matrix.

- KVL and loop matrix = KVL states that for any lumped electrical network, the algebraic sum of the voltage drops in loop is equal to zero.

$$\sum_{j=1}^N b_{kj} V_j = 0, k = 1, 2 \dots N$$

b_{kj} – branch in b_j loop l_k

Example: Find the number of links for the graph shown.

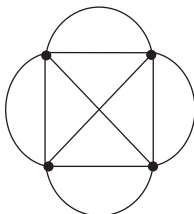


Fig. 4.7

$$L = b - n + 1 = 10 - 4 + 1 = 7$$

4.2 SOLUTION METHODS: NODAL AND MESH ANALYSIS

Kirchhoff's Law

Current law states that the algebraic sum of all branch currents entering or leaving a node is zero at all instants of time.

Charge which enters a node, must leave that node because it cannot be stored there.

$$\sum_{n=1}^N i_n = 0$$

Voltage law states that the algebraic sum of all branch voltages around a closed loop path is zero at all instants of time. It is a consequence of the law of conservation of energy.

$$\sum_{n=1}^N V_L = 0.$$

4.3 DOT CONVENTION

M-Mutual inductance and its unit is Henry.

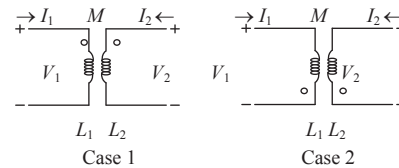


Fig. 4.8

Case 1 and 2: Effect of mutual inductance is positive when I_1 and I_2 are both entering and both leaving out of the dot.

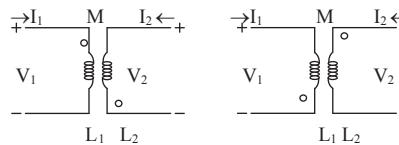


Fig. 4.9

Case 3 and 4: Effect of mutual inductance is negative when one current is entering into the dot and the second current is moving out of the dot.

KVL Equation

Case 1 and 2

$$V_1 = L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt} ; \quad V_2 = L_2 \frac{dI_2}{dt} + M \frac{dI_1}{dt}$$

If the currents are sinusoidal, then

4.4 ■ Network Theory

$$V_1 = j\omega L_1 I_1 + j\omega M I_2 \quad ; \quad V_2 = j\omega M I_1 + j\omega L_2 I_2$$

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} j\omega L_1 & j\omega M \\ j\omega M & j\omega L_2 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

Case 3 and 4

$$V_1 = L_1 \frac{dI_1}{dt} - M \frac{dI_2}{dt} \quad ; \quad V_2 = L_2 \frac{dI_2}{dt} - M \frac{dI_1}{dt}$$

If I_1 and I_2 are sinusoidal, then

$$V_1 = j\omega L_1 I_1 - j\omega M I_2$$

$$V_2 = -j\omega M I_1 + j\omega L_2 I_2$$

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} j\omega L_1 & -j\omega M \\ -j\omega M & j\omega L_2 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

where more than two inductors are coupled together a new pair of dots is needed. For each pair of inductors several kinds of dots are used.

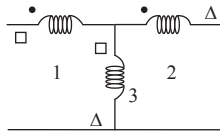


Fig. 4.10

- → coupling between coils 1 and 2;
- Δ → Represent the coupling between coils 2 and 3;
- → Represent the coupling between coils 1 and 3.

Inductance of Coupled Coils

(a) Series-aiding connection:

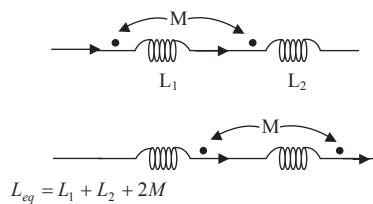


Fig. 4.11

(b) Series-opposition connection:

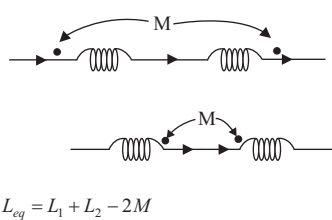
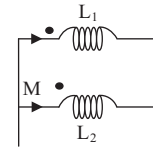


Fig. 4.12

(c) Parallel-additive coupled:



$$L_{eq} = \frac{L_1 L_2 - M^2}{L_1 + L_2 - 2M}$$

Fig. 4.13

Example:

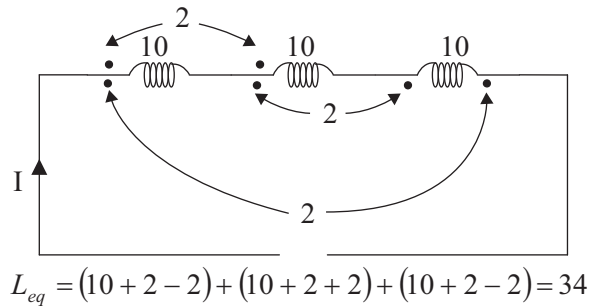
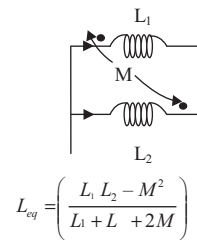


Fig. 4.14

(d) Parallel differentially coupled



$$L_{eq} = \left(\frac{L_1 L_2 - M^2}{L_1 + L_2 + 2M} \right)$$

Fig. 4.15

Magnetically coupled circuits and their equivalent circuits:

(i)

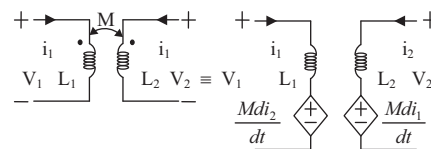


Fig. 4.16

$$V_1 = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} ;$$

$$V_2 = L_2 \frac{di_2}{dt} + M \frac{di_1}{dt}$$

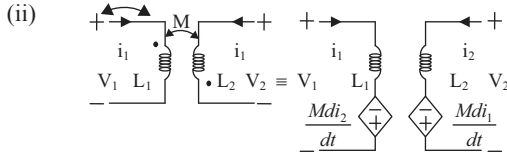


Fig. 4.17

$$V_1 = L_1 \frac{di_1}{dt} - M \frac{di_2}{dt}; \quad V_2 = L_2 \frac{di_2}{dt} - M \frac{di_1}{dt}$$

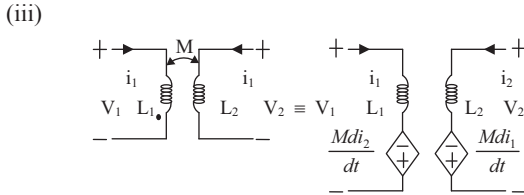


Fig. 4.18

$$V_1 = L_1 \frac{di_1}{dt} - M \frac{di_2}{dt}; \quad V_2 = L_2 \frac{di_2}{dt} - M \frac{di_1}{dt}$$

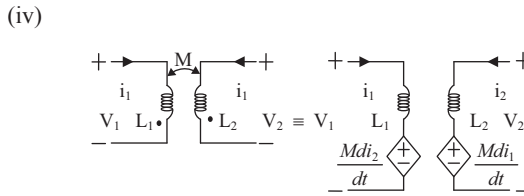


Fig. 4.19

$$V_1 = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}; \quad V_2 = L_2 \frac{di_2}{dt} + M \frac{di_1}{dt}$$

Ideal Transformer

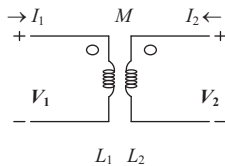


Fig. 4.20

$$L_1 = N_1^2; \quad L_2 = N_2^2$$

$$\frac{L_1}{L_2} = \frac{N_1^2}{N_2^2}; \quad L_1 N_1^2 = L_2 N_2^2$$

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \text{ and } \frac{I_1}{I_2} = \frac{-N_2}{N_1}$$

$$N_1 I_1 + N_2 I_2 = 0$$

4.4 NETWORK THEOREMS: SUPERPOSITION, THEVENIN AND NORTON'S MAXIMUM POWER TRANSFER, WYE-DELTA TRANSFORMATION

Superposition Theorem

The response in any element of a linear (R, L, C) bilateral network containing more than one source is the sum of the response produced by the sources, each acting alone, with independent voltage source, short circuit and independent current sources open circuit. The dependent current or voltage sources will remain as it is in the analysis.

The superposition does not apply to power since it is not a linear function. Power is a square of current or voltage.

- Only applicable to linear circuit.
- It states that if response of a circuit with input (x_1) is y_1 and with input (x_2) is y_2 , then output of the circuit when both inputs is applied simultaneously is given by sum of two outputs.
- For solving circuit, for applying superposition theorem, the effect of one source is taken at a time by suppressing the other source.
- Current source is opened and voltage source is shorted for suppressing the sources.
- Superposition cannot be applied directly to the computation of power as power is square of current or voltage.
- Dependent sources will remain unchanged in the analysis.

Thevenin's Theorem

A linear active network which contains one or more than one voltage or current source can be replaced by a single voltage source and a series impedance as shown in the figure.

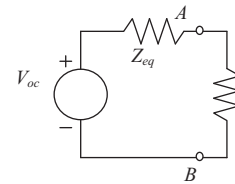


Fig. 4.21

where, V_{oc} is open circuit voltage across the terminal A and B .

Z_{eq} is equivalent impedance of the network between the terminal A and B , when all independent voltage sources are short circuited, all independent current sources are open circuited and all dependent sources are kept as it is.

R_L is that element which was removed to find V_{oc} and through which current and voltage is to be measured.

- This theorem is applied in finding the current, voltage and power in a particular element of Network.

4.6 ■ Network Theory

- First isolate the element in which current and voltage is to be found.
- From disconnected pair of terminals, reduce the circuit to a single equivalent resistance Z_{eq} after suppressing sources.
- Find open circuit voltage across that particular terminal.
- We have V_{oc} and series internal resistance Z_{eq} . O
- Equivalent circuit can be drawn finally.

Norton's Theorem

A linear active network which contains one or more than one voltage or current sources can be replaced by a single current source and a parallel impedance as shown in the figure.

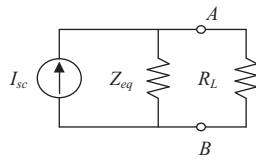


Fig. 4.22

where, I_{sc} is the current between terminal when A and B are short circuited.

Z_{eq} is as Thevenin's equivalent model.

- It is dual of Thevenin's theorem.
- After isolating the element, the terminal is shorted and the short-circuit current I_{sc} is calculated.

Maximum Power Transfer Theorem

A source with an internal impedance of $R_s + jX_s$, deliver maximum power to a load impedance Z_L .

When, $Z_L = Z_s^*$

When, Z_s^* = represents complex conjugate

If $Z_s = R_s + jX_s$, then for maximum power transfer.

$Z_L = Z_s^* = R_s - jX_s$

$R_L = R_s$ and $X_L = -X_s$.

Star-To-Delta Conversion

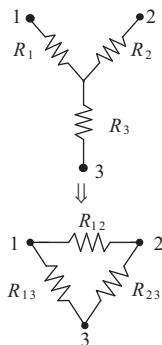


Fig. 4.23

$$R_{12} = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_3}$$

$$R_{13} = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_2}$$

$$R_{23} = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_1}$$

Delta-to-star Conversion

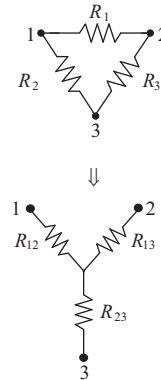


Fig. 4.24

$$R_{12} = \frac{R_1 R_2}{R_1 + R_2 + R_3}$$

$$R_{13} = \frac{R_1 R_3}{R_1 + R_2 + R_3}$$

$$R_{23} = \frac{R_2 R_3}{R_1 + R_2 + R_3}$$

4.5 STEADY STATE SINUSOIDAL ANALYSIS USING PHASORS

Phasor Diagrams

- The phasor diagram is a name given to a sketch in the complex plane showing the relationships of the phasor voltage and phasor current throughout a specific circuit.
- It also provides a graphical method for solving certain problems which may be used to check more exact analytical methods.
- It proves to be of considerable help in simplifying the analytical work in certain symmetrical poly-phase problem by enabling us to recognize the symmetry and to apply it in a helpful way.
- Phasors will be defined from the cosine function. If a voltage or current expression is in the form of a sine, it will be changed to a cosine by subtracting 90° from the phase.

- Consider the examples shown in the Table. Observe that phasors, which are vectorial in nature, are indicated by boldface capitals.
- The phase angle of the cosine function is written as the angle of the phasor. Thus the phasor diagram may be considered as a snapshot of the counter-clockwise-rotating vector taken at $t = 0$.

Sinusoidal Steady State Analysis

The table shown below shows the steady state response of passive element due to the sinusoidal excitation.

	$i = I \cos \omega t, v = V \cos \omega t$
	$v_r = RI \cos \omega t$ $i_r = \frac{V}{R} \cos \omega t$
	$v_L = \omega LI \cos(\omega t + 90^\circ)$ $i_r = \frac{V}{\omega L} \cos(\omega t - 90^\circ)$
	$v_C = \frac{1}{\omega C} \cos(\omega t + 90^\circ)$ $i_C = \omega CV \cos(\omega t - 90^\circ)$

Fig. 4.25

Resultant of Two Phasors

Phasors are like vector in two dimension space. Simple vector algebra can be used for phasor resultant calculation. Figure below explains this concept a little bit.

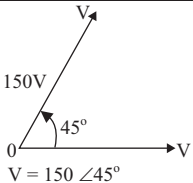
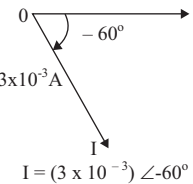
Function	Phasor Representation
$v = 150 \cos(500t + 45^\circ) \text{ (V)}$	 $V = 150 \angle 45^\circ$
$i = (3 \times 10^{-3}) \sin(2000t + 30^\circ) \text{ (A)}$ $= (3 \times 10^{-3}) \cos(2000t - 60^\circ) \text{ (A)}$	 $I = (3 \times 10^{-3}) \angle -60^\circ$

Fig. 4.26

Phasor as Complex Numbers

When the horizontal projection axis is identified with the real of the complex plane, phasors become complex numbers. Then in view of Euler's identity,

$$e^{j\theta} = \cos \theta + j \sin \theta$$

There are three equivalent notations for a phasor:

Polar form $V = V \angle \theta$

Rectangular form $V = V \cos \theta + jV \sin \theta$

Exponential form $V = V e^{j\theta}$

The polar form is a convenient way to display the two parts of a phasors; however, it does not suggest how to express the product or quotient of two phasors. The exponential form suggests that

$$V_1 V_2 = V_1 V_2 \angle (\theta_1 + \theta_2)$$

$$\frac{V_1}{V_2} = \frac{V_1}{V_2} \angle (\theta_1 - \theta_2)$$

On the other hand, the rectangular form is useful in adding or subtracting phasors.

4.6 LINEAR CONSTANT COEFFICIENT DIFFERENTIAL EQUATIONS; TIME DOMAIN ANALYSIS OF SIMPLE RLC CIRCUITS

First Order Differential Equation

The differential equation is of the form

$$K_0 \frac{di(t)}{dt} + K_1 i(t) = V(t)$$

Where, K_0, K_1 are constants.

$v(t)$ the forcing function and

$i(t)$ is the dependent variable.

R- L Network

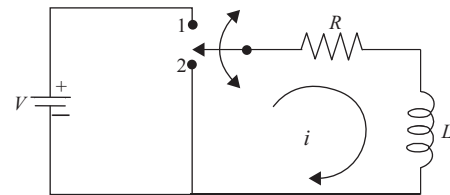


Fig. 4.27

Initially, switch is at position 1.

At time $t = 0$ it moved to position 2.

At position 2,

Apply Kirchoff's voltage law $\frac{L di}{dt} + Ri = 0$

Solution of this is $i(t) = K e^{\frac{-R}{L}t}$

at $t = 0, i(0) = \left(\frac{V}{R}\right),$

4.8 ■ Network Theory

Thus, $K = \left(\frac{V}{R} \right)$

Hence, $i(t) = \left(\frac{V}{R} e^{-\frac{R}{L}t} \right)$

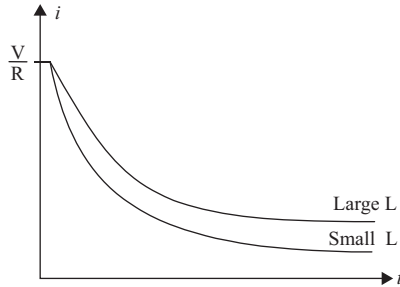


Fig. 4.28

Rate of decaying of current in R L circuit.

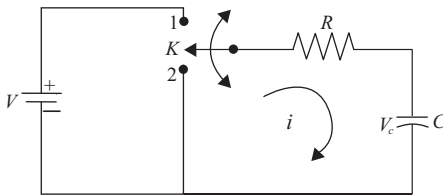


Fig. 4.29

Initially, switch is at position 1.

At time $t = 0$ it moved to position 2.

Apply kirchoff's voltage law

$$\frac{1}{C} \int_{-\infty}^t i(t) dt + Ri(t) = 0 \quad t > 0$$

Differentiating the above equation we get

$$\frac{di}{dt} + \frac{i}{RC} = 0$$

$$i = K \cdot e^{-t/RC}$$

$$i(0) = -\frac{V}{R}$$

Thus, $i(t) = -\frac{V}{R} e^{-t/RC} \quad t \geq 0$

Second Order Differential Equation

$$K_0 \frac{d^2 i}{dt^2} + K_1 \frac{di}{dt} + K_2 i = 0$$

Where, K_0 , K_1 and K_2 are some constants.

If this equation represents an electrical network, then we can say that external excitation is not present.

Solving this equation leads to characteristic equation

$$K_0 s^2 + K_1 s + K_2 = 0$$

The general solution of the differential equation is

$$i(t) = a_1 e^{s_1 t} + a_2 e^{s_2 t}$$

Example:

For the given circuit, obtain the equation of $i(t)$ and solve to find $i(t)$.

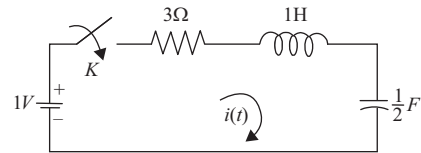


Fig. 4.30

Solution:

The differential equation for the current in the circuit is given by kirchoff's voltage law

$$L \frac{di}{dt} + Ri + \frac{1}{C} \int i dt = V$$

Differentiating this equation again

$$L \frac{d^2 i}{dt^2} + \frac{R di}{dt} + \frac{1}{C} i = 0$$

$$\frac{d^2 i}{dt^2} + \frac{R}{L} \frac{di}{dt} + \frac{1}{LC} i = 0$$

Putting value of $L = 1$, $R = 3$ and $C = \frac{1}{2}$

$$\frac{d^2 i}{dt^2} + \frac{3 di}{dt} + 2i = 0$$

Characteristic equation is

$$s^2 + 3s + 2 = 0$$

Solving this, we get $s = -1$ and -2

Thus, $i(t) = K_1 e^{-t} + K_2 e^{-2t}$

Where, K_1 and K_2 are some constant which are to found using initial condition.

Response of a Network

For a given characteristic equation,

$$s^2 + a_1 s + a_2 = 0 \text{ where, } a_1 \text{ and } a_2 \text{ are real and non-negative.}$$

Case 1:

If $a_1^2 > 4a_2$, roots are negative real and unequal, circuit is over damped circuit, solution will be form $i(t) = K_1 e^{s_1 t} + K_2 e^{s_2 t}$

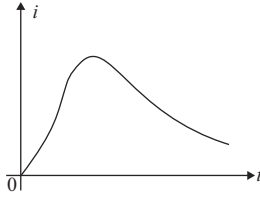


Fig. 4.31

Case 2:

If $a^2 = 4a_2$, roots are negative real and equal, circuit is critically damped, solution will be of form $i(t) = K_1 e^{s_1 t} + K_2 t e^{s_2 t}$

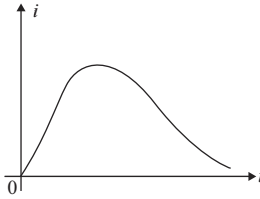


Fig. 4.32

Case 3:

If $a^2 < 4a_2$, roots are complex conjugate (real part still negative), circuit is under damped, solution will be of form.

$$i(t) = e^{\sigma t} (K_1 \cos \omega_1 t + K_2 \sin \omega_1 t)$$

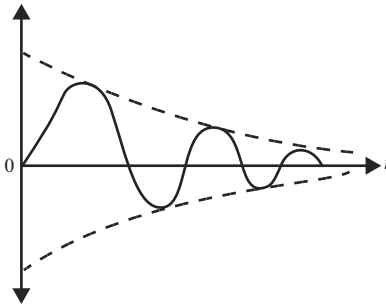


Fig. 4.33

Case 4:

If $\{a_1 = 0 \text{ and } a_2 \neq 0\}$ the roots are conjugate and purely imaginary

Circuit will be oscillatory. Solution will be of form $i = K_1 \cos \omega_1 t + K_2 \sin \omega_2 t$

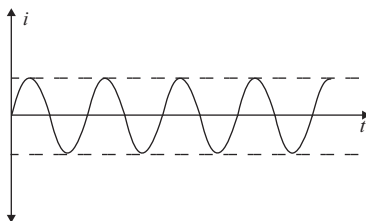


Fig. 4.34

Networks Excited By External Energy Sources

In this case, differential equation will have two solutions:

1. Complementary function
2. Particular integral.

Complementary function can be found using previous methods. Form the characteristic equation and then find its root and thus solution.

Particular integral depends on the type of energy source.

$$a_0 \frac{d^2 i}{dt^2} + a_1 \frac{di}{dt} + a_2 i = v(t)$$

$v(t)$	Particular integral
1. $V(\text{constant})$	$\rightarrow A(\text{constant})$
2. $a_1 t^n$	$\rightarrow B_0 t^n + B_1 t^{n-1} + \dots B_n$
3. $a_2 t^{rt}$	$\rightarrow C e^{rt}$
4. $a_3 \cos \omega t$	$\rightarrow D \cos \omega t + E \sin \omega t$
5. $a_4 \sin \omega t$	$\rightarrow D \cos \omega t + E \sin \omega t$
6. $a_5 t^n e^{rt} \cos \omega t$	$\rightarrow (F_1 t^n + \dots G_n) e^{rt} \sin \omega t$

The complete general solution

$$i(t) = i_c(t) + i_p(t)$$

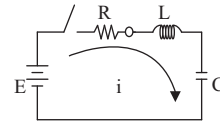
Application of Second Order Systems

Fig. 4.35

- Under damped, $\left(\frac{R}{2L}\right)^2 < \left(\frac{1}{LC}\right)$
- Critically damped, $\left(\frac{R}{2L}\right)^2 = \left(\frac{1}{LC}\right)$
- Over damped, $\left(\frac{R}{2L}\right)^2 > \left(\frac{1}{LC}\right)$
- Oscillatory $\left(\frac{R}{2L}\right) = 0$ and $\left(\frac{1}{LC}\right) \neq 0$,
- Natural frequency $\omega_n = \left(\frac{1}{\sqrt{LC}}\right)$
- Damping ratio $\delta = \left(\frac{R}{2}\right) \sqrt{\frac{C}{L}}$
- Damping co-efficient $\alpha = \left(\frac{R}{2L}\right)$
- Time constant $= \left(\frac{1}{\alpha}\right) = \left(\frac{2L}{R}\right)$.

For a Parallel Circuit of the Form

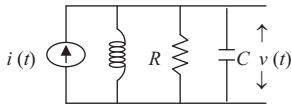


Fig. 4.36

- Natural frequency $\omega_n = \left(\frac{1}{\sqrt{LC}} \right)$

- Damping ratio $\delta = \left(\frac{1}{2R} \right) \sqrt{LC}$

- Damping coefficient $\alpha = \delta \omega_n = \left(\frac{1}{2RC} \right)$

Concept of complex frequency:

- Characteristic equation: $s^2 + 2\delta\omega_n s + \omega_n^2 = 0$

- Eigen values are

$$s_{1,2} = -\delta\omega_n \pm j\omega_n \sqrt{1-\delta^2}$$

- Radial distance between Eigen values

$$s_{1,2} \text{ from the origin is } \omega_n$$

$$(-\delta\omega_n)^2 + [\omega_n \sqrt{1-\delta^2}]^2 = \omega_n^2$$

$$(\alpha)^2 + (\omega_d^2) = \omega_n^2$$

- Root of the characteristic equation decide the dynamic behaviour of the transient response of the system.

Initial Value Theorem

If Laplace of $f(t) \leftrightarrow F(s)$ then

$$f(0) = \lim_{t \rightarrow 0} f(t) = \lim_{s \rightarrow \infty} [sF(s)]$$

Final Value Theorem

$$f(\infty) = \lim_{t \rightarrow \infty} f(t) = \lim_{s \rightarrow 0} [sF(s)]$$

Time Delay

$$(t - T) = e^{-st} F(s),$$

where, $F(s)$ is Laplace of $f(t)$.

Initial and final condition in electronic network

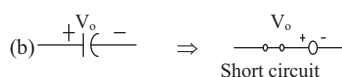
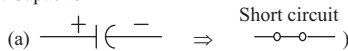
Case 1:

Initial condition, i.e.,
 $t = 0.$

1. Resistance



2. Capacitor



3. Inductor

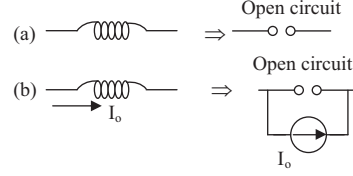
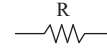


Fig. 4.37

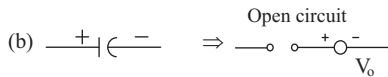
Case 2:

Final condition i.e., $t \rightarrow \infty$, i.e., steady state.

1. Resistance



2. Capacitor



3. Inductor

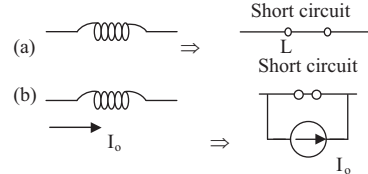


Fig. 4.38

Application of First Order Systems

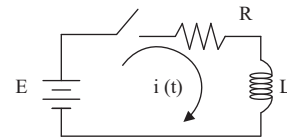


Fig. 4.39

- $V_r(t) = E [1 - \exp(-R.t/L) = E (1 - e^{-t/\tau})]$
- Time constant $\tau = (L/R)$
- Steady state value $= (E/R) (1 - e^{-t/\tau})$
- Transient current $i(t) = (E/R) \{1 - \exp[(-R.t)/L]\}$
 $V_L(t) = Ee^{-t/\tau}$
- Capacitor behaves like a short at the time of switching on at $t = 0$ (inductor is open at $t = 0$).
- Capacitor is open at $t \rightarrow \infty$ it behaves as open circuit. (L is short at $t = \infty$).

Second Order Systems

- Transfer function

$$F(s) = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

- $\alpha = \delta \omega_n$ called damping coefficient, it controls, the rate and rise of decay of time response.
- Time constant $= (1/\alpha)$
- ω_d damped frequency $\omega = \omega_n \sqrt{1 - \delta^2}$
 - (a) $0 < \delta < 1$, under damped case.
 - (b) $\delta = 1$, critically damped case.
 - (c) $\delta > 1$, over damped case.
 - (d) $\delta = 0$, un damped case.
 - (e) $\delta < 0$, negatively damped case.

4.7 RESONANCE

It is a condition when the voltage across a circuit becomes in phase with the current supplied to the circuit. At resonance, the circuit behaves like a resistive circuit.

Power factor of the circuit at resonance becomes unity “1”.

Series Resonance (RLC Series Circuit)

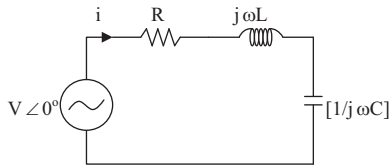


Fig. 4.40

The total impedance of series network is given by

$$\begin{aligned} \frac{V}{1} &= R + j(X_L - X_C) \\ &= R + j\left[\omega L - \frac{1}{\omega C}\right] \end{aligned}$$

where, $X_L = \omega L$ $X_C = \frac{1}{\omega C}$

$$|Z| = \sqrt{R^2 + (X_L - X_C)^2}$$

At resonance

$$\text{Im}\{Z\} = 0$$

$$X_L - X_C = 0$$

$$\omega_0 = \frac{1}{\sqrt{LC}} \rightarrow \text{resonant frequency of the circuit}$$

$$\therefore f_0 = \frac{1}{2\pi\sqrt{LC}}$$

where, f_0 is the frequency of resonance in Hertz.

$$\therefore \text{At resonance, the current is } I_0 = \frac{V}{R}$$

Variation in Z with respect to ‘ ω ’

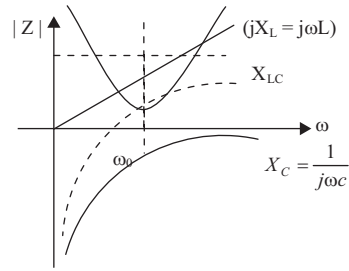


Fig. 4.41

Note: $\omega_1 < \omega_0$ behaves like RC capacitive circuit.

$\omega > \omega_0$ behaves like RL inductive circuit

$\omega = \omega_0$ behaves like resistive circuit.

- Impedance of series RLC circuit is minimum at resonance frequency $\omega = \omega_0$.
- At resonant frequency $Z = R$.
- Current in series RLC circuit is maximum at resonance frequency.

Selectivity and Bandwidth

Selectivity of a resonant circuit is defined as the ratio of resonant frequency to the BW. Thus,

$$\text{Selectivity} = \frac{\text{Resonance frequency}}{\text{Bandwidth}} = \frac{f_0}{f_2 - f_1}$$

Q-Factor

$$Q = 2\pi \left(\frac{\text{max. energy stored}}{\text{energy dissipated/cycle}} \right)$$

* Q of an inductor L with resistor $R = \frac{\omega L}{R}$

* Q of a capacitor C with effective internal resistor

$$R = \frac{I}{\omega CR}$$

* Q of a leaky capacitor which is represented by a capacitor C with high resistance R_p in shunt $= \omega CR_p$.

Circuit Magnification Factor

A resonance, $I_0 = V/R$ is the current in the circuit, where the voltage across the inductor at resonance is given by

$$V_L = I_0 X_L = (V/R) \omega_0 L = Q_0 V$$

Similarly, the voltage across the capacitor at resonance is given by

$$V_C = I_a X_C = \frac{V}{R} \times \frac{1}{\omega_0 C} = Q_0 V$$

$$Q_C = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 CR}$$

Q_0 is called the circuit magnification factor. Thus at resonance, the voltage across L and C is equal to Q times the applied voltage V . As $Q > 1$, the voltage across L and C is magnified by Q times the applied voltage.

Also $Q_0 = \frac{f_0}{\Delta f}$ i.e., the larger the value of Q_0 , the lesser will be the bandwidth. The more selective the circuit, the lesser will be the bandwidth. Δf varies inversely with Q_0 .

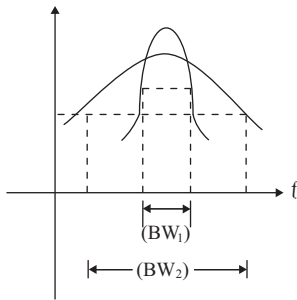


Fig. 4.42

Selectivity increases with decreasing bandwidth. For series Resonant circuit at $\omega = \omega_0$

$$Q = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 CR} = \frac{1}{R} \sqrt{\frac{L}{C}}$$

$$\text{For series RLC circuit } BW = (\omega_2 - \omega_1) = \frac{R}{L}$$

Parallel RLC Resonance Circuit

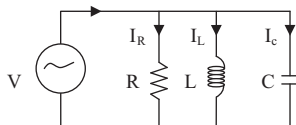


Fig. 4.43

Admittance of circuit

$$\frac{1}{V} = \frac{1}{R} + j\left(\omega C - \frac{1}{\omega L}\right) = Y$$

At resonance

$$\text{Im}\{Y\} = 0$$

$$\omega_0 C - \frac{1}{\omega_0 L} = 0$$

$$\therefore \omega_0 = \frac{1}{\sqrt{LC}} \quad (\omega_0 \rightarrow \text{resonant frequency}) \text{ at resonance}$$

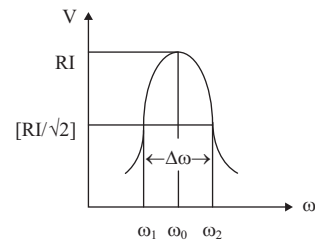
$$Y = \frac{1}{R}$$

$$\Rightarrow Z = R$$

Properties of Second-Order Parallel RLC Resonant Circuit

A circuit consisting of a parallel connection of a resistor, R , an inductor L , and a capacitor C is called a second order parallel resonant circuit are as follows:

- The resonant frequency is $\omega_0 = \frac{1}{\sqrt{LC}}$ rad/s.
- Below resonance, the circuit acts like an RL circuit.
- Above resonance, the circuit acts like an RC circuit.
- If the conductance is zero (the resistance is infinite) at resonance, the circuit acts like an open circuit.
- The bandwidth is $\frac{1}{RC}$.
- The quality factor Q_{op} is $R\sqrt{\frac{C}{L}}$.



Variation of $|V|$ with ω and $|V|$ is maximum at resonance

Fig. 4.44

Note: Impedance of parallel resonant circuit is maximum at resonance.

Current of parallel resonant circuit is minimum at resonance.

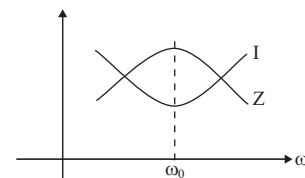


Fig. 4.45

$$\text{At } I = \frac{V}{R}$$

Practical Parallel Resonant Circuit

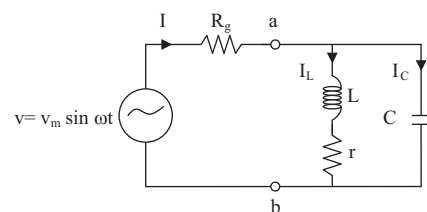


Fig. 4.46

A parallel resonant or anti-resonant circuit consists of an inductance L in parallel with a capacitor C . A small resistance r associated with L and C is assumed to be lossless. The tuned circuit is driven by a voltage source $v = V_m \sin \omega t$. R_g is the generator resistance. I_c and I_L are the current through capacitor and inductor respectively. At resonance $Z_o = \frac{L}{Cr}$

Admittance of circuit

$$\frac{I}{V} = j\omega C + \left(\frac{1}{r + j\omega L} \right) = j\omega C + \frac{r - j\omega L}{(r^2 + \omega^2 L^2)}$$

$$= \frac{r}{r^2 + \omega^2 L^2} + j \left(\omega C - \frac{\omega L}{r^2 + \omega^2 L^2} \right)$$

At resonance

$$\text{Im}(Y) = 0$$

$$\omega_0 C - \frac{\omega^2 L}{r^2 + \omega^2 L^2} = 0$$

$$\omega_0 C = \frac{\omega^2 L}{r^2 + \omega_0^2 L^2}$$

$$\omega_0 = \frac{1}{LC} - \frac{r^2}{L^2}; \quad \omega_0 = \sqrt{\frac{1}{LC} - \frac{r^2}{L^2}}$$

This is also called anti resonant frequency.

At resonance

$$\text{Re}\{Y\} = \frac{r}{r^2 + \omega_0^2 L^2} = \frac{r}{r^2 + \left[\frac{1}{LC} - \frac{r^2}{L^2} \right] L^2} = \frac{r}{(L/C)}$$

$$\therefore \text{Re}\{Y\} = \frac{Cr}{L} = Y_0$$

$$\text{At resonance } Z_0 = \frac{L}{Cr}$$

Variation of Relative Impedance

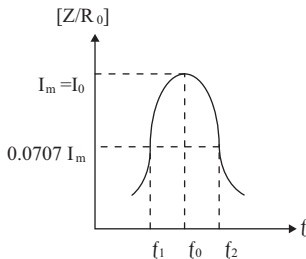


Fig. 4.47

Selectivity and Bandwidth

Q factor of practical resonant circuit at resonance frequency

$$Q = \frac{\omega_0 L}{r} = \frac{1}{\omega_0 C_r} = \frac{1}{r} \sqrt{\frac{L}{C}}$$

[No change form series resonant circuit].

The higher the Q , the more selective will be the circuit and the lesser will be the bandwidth (BW)

4.8 TWO-PORT NETWORK PARAMETERS

Driving Point and Transfer Functions

Network Function



Fig. 4.48

Driving Point Impedance and Admittance Function

(a) Driving impedance function at port 1: $Z_{11}(s) = \frac{V_1(s)}{I_1(s)}$

(b) Driving impedance function port 2: $Z_{22}(s) = \frac{V_2(s)}{I_2(s)}$

(c) Driving admittance function port 1: $Y_{11}(s) = \frac{I_1(s)}{V_1(s)}$

(d) Driving admittance function at port 2: $Y_{22}(s) = \frac{I_2(s)}{V_2(s)}$

Note: $Z_{11} = \frac{1}{Y_{11}}; \quad Z_{22} = \frac{1}{Y_{22}}$

Impedance and Admittance Transfer Function

(a) $Z_{21}(s) = \frac{V_2(s)}{I_1(s)}; \quad (b) \quad Z_{12}(s) = \frac{V_1(s)}{I_2(s)}$

(c) $Y_{21}(s) = \frac{I_2(s)}{V_1(s)}; \quad (d) \quad Z_{12}(s) = \frac{I_1(s)}{V_2(s)}$

Note: Numerator carries response and denominator carries excitation.

Voltage and current transfer function

(a) Voltage transfer function

1. $G_{21}(s) = \frac{V_2(s)}{V_1(s)}; \quad 2. \quad G_{12}(s) = \frac{V_1(s)}{V_2(s)}$

(b) Current transfer function

1. $\alpha_{21} = \frac{I_2(s)}{I_1(s)}; \quad 2. \quad \alpha_{12} = \frac{I_1(s)}{I_2(s)}$

Consider a Network Function

$$H(s) = \frac{a_0 s^n + a_1 s^{n-1} + \dots + a_n}{b_0 s^m + b_1 s^{m-1} + \dots + b_m}$$

$$= \frac{(a_0 - b_0) \left[(s - Z_1)(s - Z_2)(s - Z_3) \dots (s - Z_N) \right]}{\left[(s - P_1)(s - P_2) \dots (s - P_m) \right]} = \frac{P(s)}{Q(s)}$$

Properties of Driving Point Impedance and Admittance Functions or Necessary Conditions for Driving Point Impedance and Admittance Function.

1. All coefficients of $P(s)$ and $Q(s)$ must be positive and real.
2. Complex and imaginary poles and zeros must be conjugate

$$\text{i.e., } F(s) = \frac{s+1}{(s+3)(s+1-j)}$$

is not a driving point impedance function.

3. (a) Real part of all poles and zeros must not be positive.
(b) If poles and zeros are imaginary, they must be simple (non-repeated).
4. There should not be any missing power of 's' between highest and lowest power in numerator and denominator both except when either all even or odd power are missing.
5. The degree of $P(s)$ and $Q(s)$ can at the most differ by 1.
6. Lowest power of s in numerator and denominator can differ at most '1'.

Necessary Conditions for Transfer Function

1. The coefficients in the polynomials $P(s)$ and $Q(s)$ of $H(s) = P(s)/Q(s)$ must be real and those for $Q(s)$ must be positive.
2. Poles and zeros which are complex and imaginary must be conjugate.
3. The real part of the poles must be either negative or zero, if poles are imaginary, then they must be simple (non-repeated). But zeros can have positive real part also.
4. There should not be any missing power of s between lowest and highest power of s in denominator except all odd and all even powers are missing. Numerator can have i.e., $(P(s))$ can have missing terms of s and some of the coefficients of may be negative.
5. The degree of $P(s)$ may be as small as zero independent of the degree of $Q(s)$.
6. (a) For G_{12} and α_{12} , the maximum degree of $P(s)$ is the degree of $Q(s)$.
(b) For Z_{12} and Y_{12} the maximum degree of $P(s)$ is the degree of $Q(s)$ plus one.

Matrix Method for Determination of Network Functions

1. Determination of impedance function from nodal analysis

$$I = YV$$

$$Z_{jk} = \frac{\Delta_{kj}}{\Delta}$$

where, $\Delta = |Y|$ and $\Delta_{kj} = \text{co-factor}$

$$= (-1)^{k+j} M_{kj}$$

M_{kj} is minor a_{kj} element of $|Y|$.

2. Determination of admittance function from mesh analysis

$$V = ZI$$

$$Y_{jk} = \frac{\Delta_{kj}}{\Delta}$$

where, $\Delta = |Z|$ and $\Delta_{kj} = (-1)^{k+j} M_{kj}$.

3. Determination of current transfer function mesh analysis

$$V = ZI$$

$$\alpha_{12} = \frac{\Delta_{12}}{\Delta_{11}}$$

$$\Delta_{kj} = (-1)^{k+j} M_{kj}$$

M_{kj} -minor of element a_{kj} of $|Z|$.

4. Determination of voltage transfer function Nodal analysis

$$I = YV ; G_{12} = \frac{\Delta_{12}}{\Delta_{11}}$$

$$\Delta_{kj} = (-1)^{k+j} M_{kj}$$

M_{kj} Minor of element of a_{kj} of $|Y|$.

Impedance Matrix of Gyrator

- It is a device that gyrates the current of one port into a voltage at the other and vice versa.

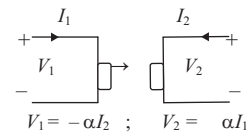
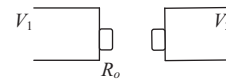


Fig. 4.49

As impedance transforming element.



$$V_1 + R_o I_2 = 0$$

$$V_2 = R_o I_1$$

Fig. 4.50

- Matrix form $\begin{bmatrix} 0 & -\alpha \\ \alpha & 0 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$.
- If the gyrator is terminated in an impedance Z_L , the driving point impedance

$$Z_d = \frac{Z_{11} Z_L + \Delta_z}{Z_{22} + Z_L} ; Z_{in} = (\alpha^2 / Z_L).$$

- If Z_L is capacitor, then $Z_L = (1/sC)$
 $Z_{in} = sC\alpha^2$ give inductor of value $= \alpha^2 C$.
- If Z_L is an inductor $Z_L = sL$
 $Z_{in} = (\alpha^2/s_L)$ gives capacitor of value $= (L/\alpha^2)$.
- Used to simulate inductor from capacitor.

Network Transfer Functions

- A transfer function is the ratio of Laplace transform of the output $Y(s)$ to Laplace transform of the input $X(s)$.
- By setting the denominator of the transfer function to zero, and obtaining the roots by solving the equation, we can know the system's stability by considering by setting $s = 0$, i.e., $G(0)$ give DC gain where $G(s)$ is transfer function.

Z or Impedance Parameters

In this, the dependent variables are V_1 and V_2 and independent variable I_1 , and I_2 .

Defining equations are:

$$V_1 = Z_{11} I_1 + Z_{12} I_2 \quad V_2 = Z_{21} I_1 + Z_{22} I_2$$

In Impedance Matrix Form

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

- To obtain the Z-parameters, we open circuit the output and input port alternately.
- With output open circuit $I_2 = 0$

$$V_1 = Z_{11} I_1$$

$$\text{or } Z_{11} = \left. \frac{V_1}{I_1} \right|_{I_2=0} = \text{input impedance}$$

$$V_2 = Z_{21} I_1$$

$$\text{or } Z_{21} = \left. \frac{V_2}{I_1} \right|_{I_2=0} = \text{forward transfer impedance}$$

- With input open circuit $I_1 = 0$

$$V_1 = Z_{12} I_2$$

$$Z_{12} = \left. \frac{V_1}{I_2} \right|_{I_1=0} = \text{reverse transfer impedance}$$

$$V_2 = Z_{22} I_2$$

$$Z_{22} = \left. \frac{V_2}{I_2} \right|_{I_1=0} = \text{output impedance.}$$

Z-parameter for a T-network

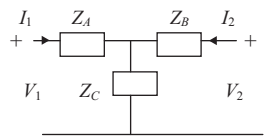


Fig. 4.51

$$Z = \begin{bmatrix} Z_A + Z_C & Z_C \\ Z_C & Z_B + Z_C \end{bmatrix}$$

Properties of Z-parameter

- Z_{11} , Z_{22} are called **driving point input and output impedance function**.
- Z_{12} and Z_{21} are called **transfer function**.
- Network for which $Z_{11} = Z_{22}$ called as **symmetrical**.
- Network for which $Z_{12} = Z_{21}$ are known as **reciprocal network**.
- Reciprocal network need not be symmetrical.

Y or Admittance Parameter

- Also known as admittance parameter.
- Independent variables are voltage V_1 , V_2 and dependent variable current I_1 , I_2 .
- $I_1 = Y_{11} V_1 + Y_{12} V_2$
 $I_2 = Y_{21} V_1 + Y_{22} V_2$.
- Admittance in matrix form

$$Y = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}$$

- For reciprocal $Y_{12} = Y_{21}$.

Symmetric

A two port is symmetric if the port can be interchanged without any effect on the performance.

$$Z_{11} = Z_{22} \\ Y_{11} = Y_{22}$$

Hybrid (h) Parameters

Current (I_1) and voltage (V_2) are the independent variable and current (I_2) and voltage (V_1) are dependent variable.

$$V_1 = h_{11} I_1 + h_{12} V_2 \\ I_2 = h_{21} I_1 + h_{22} V_2$$

Inverse Hybrid Parameter (g-parameter)

$$I_1 = g_{11} V_1 + g_{12} I_2 \\ V_2 = g_{21} V_1 + g_{22} I_2$$

Transmission Parameters (ABCD-parameters)

- It relates the voltage and current at input port to voltage and current at output port.
- $V_1 = AV_2 - BI_2$
 $I_1 = CV_2 - DI_2$.
- For symmetrical Network $A = D$.
- For reciprocal $\begin{bmatrix} A & B \\ C & D \end{bmatrix} = 1$
 = i.e., $AD - BC = 1$.

CASCADING

Two port network connected in cascade

Overall $ABCD$ parameter of two cascaded two port network is multiplication of their $ABCD$ parameters.

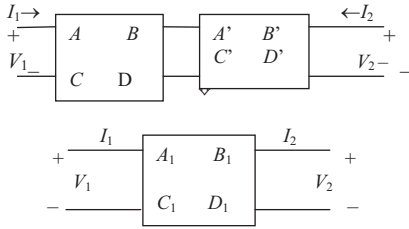


Fig. 4.52

$$\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \times \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix}.$$

Two port network in parallel

Overall matrix for two, port network connected in parallel is the sum of the individual network y -parameters ($y = (y_A) + (y_B)$) where,

(y) = overall y -parameter of combine network.

(y_A) = y -parameter of network A .

(y_B) = y -parameter of network B .

Two port network connected in series

The overall matrix for two-port network connected in series is equal to the sum of the individual network Z -parameter matrix.

$$(z) = (z_A) + (z_B).$$

4.9 STATE EQUATIONS FOR NETWORKS

State Space Representation for Electrical Network

The writing of state equation depends on the storage elements (i.e., the initial value of the inductor current i_L and capacitor voltage V_c)

because the state of the system varies from time to time as the energy on the element varies. *There are as many state variable as there are energy storing elements.*

Example:

Write the state equation for series RLC circuit.

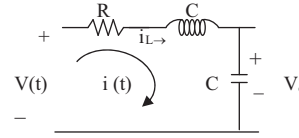


Fig. 4.53

Solution:

Corresponding to two storage elements L and C , we may choose i_L and V_c as state variable and write dynamic equation by employing KVL and KCL

$$L \frac{di_L}{dt} + R i(t) + V_c = V(t)$$

$$\text{and} \quad C \frac{dV_c}{dt} = i(t)$$

Rearranging by putting chosen state variable on LHS and network variable on RHS of equation.

$$\frac{di_L}{dt} = -\frac{R}{L} i(t) - \frac{1}{L} V_c + \frac{V(t)}{L};$$

$$\frac{dV_c}{dt} = \frac{i(t)}{C}$$

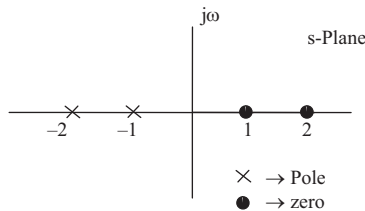
We can rewrite the two equation in matrix form.

$$\begin{pmatrix} \frac{di_L}{dt} \\ \frac{dV_c}{dt} \end{pmatrix} = \begin{pmatrix} -\frac{R}{L} & -\frac{1}{L} \\ \frac{1}{C} & 0 \end{pmatrix} \begin{pmatrix} i_L \\ V_c \end{pmatrix} + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} v(t)$$

QUESTION BANK

LEVEL 1

- Under conditions of maximum power transfer from an ac source to a variable load
 - The load impedance must also be inductive, if the generator impedance is inductive
 - The sum of the source and load impedance is zero
 - The sum of the source reactance and load reactance is zero
 - The load impedance has the same phase angle as the generator
- When a number of 2-port networks are connected in cascade the individual
 - Z_{oc} matrices are added
 - Y_{sc} matrices are added
 - Chain matrices are multiplied
 - H-matrices are multiplied
- The coupling between two magnetically coupled coils is said to be ideal if the coefficient of coupling is
 - zero
 - 0.5
 - 1
 - 2
- The pole-zero configuration of a network transfer function is shown in the given figure. The magnitude of the transfer function will



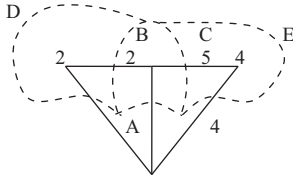
- Decrease with frequency
 - Increase with frequency
 - Initially increase and then decrease with frequency
 - Be independent of frequency
- The driving point impedance of a one-port reactive network is given by
 - $\frac{(s^2 + 1)(s^2 + 2)}{s(s^2 + 3)(s^2 + 4)}$
 - $\frac{(s^2 + 1)(s^2 + 3)}{s(s^2 + 2)(s^2 + 4)}$
 - $\frac{(s^2 + 1)}{(s^2 + 2)(s^2 + 3)}$
 - $\frac{1}{s + 1}$
 - Two two-port networks with transmission parameters A_1, B_1, C_1, D_1 and A_2, B_2, C_2, D_2 respectively are cascaded. The transmission parameter matrix of the cascaded network will be

- $\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} + \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$
- $\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$
- $\frac{A_1 A_2}{C_1 C_2} \frac{B_1 B_2}{D_1 D_2}$
- $\begin{bmatrix} (A_1 A_2 + C_1 C_2) & A_1 A_2 - B_1 D_2 \\ (C_1 A_2 - D_1 C_2) & (C_1 C_2 + D_1 D_2) \end{bmatrix}$

- For $V(s) = \frac{(s+2)}{s(s+1)}$, the initial and final value of $v(t)$ will be respectively
 - 1 and 1
 - 2 and 2
 - 2 and 1
 - 1 and 2
- The network function $F(s) = \frac{(s+2)}{(s+1)(s+3)}$ represents an
 - RC impedance
 - RL impedance
 - RC impedance and an RL admittance
 - RC admittance and an RL impedance
- In a linear network, the ratio of voltage excitation to current response is unaltered when the position of excitation and response are interchanged. This assertion stems from the
 - Principle of duality
 - Reciprocity theorem
 - Principle of superposition
 - Equivalence theorem
- If the step response of an initially relaxed circuit is known, then the ramp response can be obtained by
 - Integrating the step response
 - Differentiating the step response
 - Integrating the step response twice
 - Differentiating the step response twice
- If a capacitor is energized by a symmetrical square wave current source, then the steady-state voltage across the capacitor will be a
 - square wave
 - Triangular wave
 - step function
 - Impulse function
- A transfer function has its zero in the right-half of the s -plane. The function
 - Is positive real
 - Will give stable impulse response
 - Is minimum phase
 - Is non-minimum phase

4.18 ■ Network Theory

13. The connected planar network has four nodes and five elements. The number of meshes in its dual network is



- (a) 4 (b) 3
(c) 3 (d) 1
14. A square wave is fed to an RC Circuit. Then
(a) Voltage across R is square and across C is not square
(b) Voltage across C is not square and across R is not square
(c) Voltage across both R and C is square
(d) Voltage across both R and C is not square
15. A high Q coil has
(a) large bandwidth
(b) high losses
(c) low losses
(d) flat response
16. When Q factor of a circuit is high, then
(a) Power factor of the circuit is high
(b) Impedance of the circuit is high
(c) Band width is large
(d) None of these
17. Real part of admittance is and the imaginary part is
(a) Impedance, resistance
(b) Resistance, impedance
(c) Susceptance, inductance
(d) Conductance, susceptance
18. The network has ten nodes and seventeen branches. The number of different node pair voltage would be
(a) 7 (b) 9
(c) 10 (d) 45
19. A capacitor used for power factor correction is single-phase circuit decreases
(a) The power factor
(b) The line current
(c) Both the line current and the power factor
(d) The line current and increases power factor
20. For a two-port reciprocal network, the output-circuit voltage divided by the input current is equal to
(a) B (b) z_{12}
(c) $1/y_{12}$ (d) h_{12}
21. The impedance matrices of two, two-port network are given by

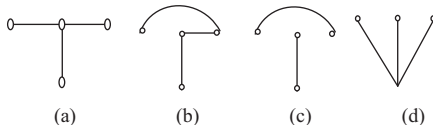
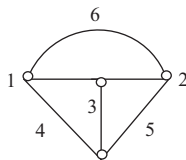
$$\begin{bmatrix} 3 & 2 \\ 2 & 3 \end{bmatrix} \text{ and } \begin{bmatrix} 15 & 5 \\ 5 & 25 \end{bmatrix}$$

If these two networks are connected in series, the impedance matrix of the resulting two port work will be

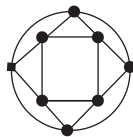
- (a) $\begin{bmatrix} 3 & 5 \\ 2 & 25 \end{bmatrix}$ (b) $\begin{bmatrix} 18 & 7 \\ 7 & 28 \end{bmatrix}$
(c) $\begin{bmatrix} 13 & 2 \\ 5 & 3 \end{bmatrix}$ (d) Indeterminate

22. A network contains only independent current sources and resistance. If the values of all resistors are doubled, the values of the node voltages
(a) Will become half
(b) Will remain unchanged
(c) Will become double
(d) Cannot be determined unless the circuit configuration and the values of the resistors are known
23. Two coils have self-inductances of 0.09 H and 0.01 H and a mutual inductance of 0.015 H. The coefficient of coupling between coils is
(a) 0.060 (b) 0.5
(c) 1.0 (d) 0.05
24. In a linear circuit the superposition principle can be applied to calculate the
(a) Voltage and power
(b) Voltage and current
(c) Current and power
(d) Voltage, current and power
25. A resistor R of 1Ω and two inductors L_1 and L_2 of inductances 1H and 2H, respectively, are connected in parallel. At some time, the currents through L_1 and L_2 are 1 A and 2 A, respectively. The current through R at time $t = \infty$ will be
(a) Zero (b) 1 A
(c) 2 A (d) 3 A
26. The dual of a parallel R - C circuit is a
(a) Series R - C circuit (b) Series R - L circuit
(c) Parallel R - C circuit (d) Parallel R - L circuit
27. Driving point impedance $Z(s) = s \left(\frac{s^2 + 1}{s^2 + 4} \right)$ is not realizable because the
(a) Number of zero is more than the number of poles
(b) Poles and zero lie on the imaginary axis
(c) Poles and zeros do not alternate on imaginary axis
(d) Neither as an impedance nor as an admittance
28. The energy stored per unit volume in an electric field (with usual notations) is given by
(a) $2 \epsilon H^2$ (b) $1/2 \epsilon H$
(c) $1/2 \epsilon E^2$ (d) ϵH^2
29. Which one of the following statement is not a property of R - L driving point impedance?
(a) The first critical frequency at the origin is a zero
(b) The last critical frequency is a pole
(c) The impedance at $S = \infty$ is always less than the impedance at $S = \text{zero}$
(d) The slope of the impedance curve is positive at all points

30. In a network containing resistances and reactances, the roots of the characteristic equation given for the circuit
 (a) The forced response (b) The total response
 (c) The natural response (d) The damped response
31. Two rectangular waveforms of duration T_1 and T_2 seconds are convolved. What is the shape of the resulting waveform?
 (a) Triangular (b) Rectangular
 (c) Trapezoidal (d) Semi-circular
32. Which one of the following statements is correct?
 In a four-branch parallel circuit, 50 mA current flows in each branch. If one of the branches opens, the currents in the other branches
 (a) Increase (b) Decrease
 (c) Are unaffected (d) Double
33. Which one of the following statements is correct?
 The poles and zeros of the driving point reactance function of an L - C network
 (a) be on the real axis of the s -plane
 (b) alternate
 (c) lie on the unit circle
 (d) are arbitrary
34. Consider the following graph:
 Which one of the following is not a tree of the below graph?



35. Consider a spanning tree of the connected graph.

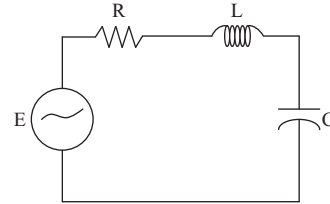


What is the number of fundamental cut-sets?

- (a) 15 (b) 16
 (c) 8 (d) 7
36. For a network of eleven branches and six nodes, what is the number of independent loops?
 (a) 4 (b) 5
 (c) 6 (d) 11
37. Which one of the following statements is not correct?
 (a) A tree contains all the vertices of its graph
 (b) A circuit contains all the vertices of its graph

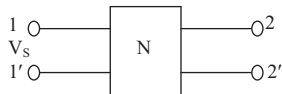
- (c) The number of f -circuits is the same as the number of chords
 (d) There are at least two edges in a circuit

38. Which one of the following statements is not correct for the circuit shown below at resonant frequency?



- (a) The current is maximum
 (b) The equivalent impedance is real
 (c) The inductive and capacitive reactances are equal in magnitude
 (d) The quality factor equals $\frac{1}{R} \sqrt{\frac{C}{L}}$.
39. Which of the following theorems can be applied to any network-linear or non-linear, active or passive, time-variant or time-invariant?
 (a) Thevenin theorem (b) Norton theorem
 (c) Tellegen theorem (d) Superposition theorem
40. The circulating current in a parallel LC circuit at any resonant frequency is
 (a) Directly proportional to frequency
 (b) Inversely proportional to frequency
 (c) Independent of frequency
 (d) None of the above
41. A network having n nodes and b branches will have
 (a) $(b + n)$ links (b) $(b - n + 1)$ links
 (c) $(b + n - 1)$ links (d) $(b + n + 1)$ links
42. Attenuator is a
 (a) Pure resistance network producing a constant attenuation
 (b) Pure resistance network producing a variable attenuation at variable frequencies
 (c) Pure resistance producing a constant attenuation at all frequencies
 (d) Pure resistance producing a constant attenuation at low frequencies
43. Decibel is the unit adopted for the gain or attenuation of communication equipment because
 (a) Total gain can be found by addition
 (b) Changes on a logarithmic scale can be perceived more easily than on a linear scale
 (c) Vision is more sensitive to the eye
 (d) The minimum changes that can be perceived by the ear
44. A high Q coil has
 (a) Large bandwidth (b) High losses
 (c) Low losses (d) Flat response

45. When Q factor of a circuit is high, then
 (a) Power factor of the circuit is high
 (b) Impedance of the circuit is high
 (c) Bandwidth is large
 (d) None of these
46. A network N' is dual of network N if
 (a) Both of them have same mesh equations
 (b) Both of them have the same node equations
 (c) Mesh equations of one are the node equations of the other
 (d) KCL and KVL equations are the same
47. The Q of a radio coil
 (a) Is independent of frequency
 (b) Increases monotonically as frequency increases
 (c) Decreases monotonically as frequency increases
 (d) Increases up to a certain frequency and then decreases beyond that frequency
48. "In any network of linear impedances, the current flowing at any point is equal to the algebraic sum of the currents caused to flow at the point by each of the sources of emf taken separately with all other emf's reduced to zero
 This statement represents:
 (a) Kirchhoff's law (b) Norton's theorem
 (c) Thevenin's theorem (d) Superposition theorem
49. Which of the following theorems is a manifestation of the Law of conservation of energy?
 (a) Tellegen's theorem (b) Reciprocity theorem
 (c) Thevenin's theorem (d) Norton's theorem
50. The voltage transfer ratio of two-part network connected in cascade may be conveniently obtained from the



- (a) Product of the individual $ABCD$ matrices of the two networks
 (b) Product of voltage transfer ratios of the two individual networks
 (c) Sum of the Z -matrices of the two networks
 (d) Sum of the h -matrices of the two networks
51. The transfer function of a low pass RC network is
 (a) $RCs/(1 + RCs)$ (b) $1/(1 + RCs)$
 (c) $RC/(1 + RCs)$ (d) $s/(1 + RCs)$
52. The hot resistance of the filament of a bulb is higher than the cold resistance because the temperature coefficient of the filament is
 (a) negative (b) infinite
 (c) zero (d) positive
53. For a second order system, if both the roots of the characteristic equation are real, then the value of damping ratio will be
 (a) less than unity (b) equal to unity
 (c) equal to zero (d) greater than unity
54. A pole of driving point admittance function implies
 (a) Zero current for a finite value of driving voltage
 (b) Zero voltage for a finite value of driving current
 (c) An open circuit condition
 (d) None of (a), (b) and (c) mentioned in the question
55. Cauer and Foster forms of realizations are used only for
 (a) Driving point reactance functions
 (b) Transfer reactance functions
 (c) Driving point impedance functions
 (d) Transfer impedance functions
56. Superposition theorem is not applicable for
 (a) Voltage calculations (b) Bilateral elements
 (c) Power calculations (d) Passive elements
57. At resonant frequency a R - L - C series circuit draws maximum current due to the reason that
 (a) the difference between capacitance reactance and inductance reactance is zero
 (b) the impedance is more than resistance
 (c) the voltage across the capacitor equal the applied voltage
 (d) the power factor is less than unity
58. When two-Wattmeter method of measurement of power is used to measure power in a balanced three phase circuit; if the Wattmeter reading is zero, then
 (a) power consumed in the circuit is zero
 (b) power factor of the circuit is zero
 (c) power factor is unity
 (d) power factor is 0.5
59. For a given voltage, four heating coils will produce maximum heat when connected
 (a) All in parallel
 (b) All in series
 (c) With two parallel pairs in series
 (d) One pair in parallel with the other two in series
60. A low-pass filter circuit is basically
 (a) A differentiating circuit with low time constant
 (b) A differentiating circuit with large time constant
 (c) An integrating circuit with low time constant
 (d) An integrating circuit with large time constant
61. The first critical frequency nearest the origin of the complex frequency plane for an R - L driving point impedance function will be
 (a) A zero in the left-half plane
 (b) A zero in the right-half plane
 (c) A pole in the left-half plane
 (d) Either a pole or zero in the left-half plane depending on the connection
62. Substitution Theorem applies to
 (a) Linear networks
 (b) Nonlinear networks
 (c) Linear time-invariant networks
 (d) Any networks

63. A two-terminal black box contains a single element, which can be R , L , C or M (mutual inductance). As soon as the box is connected to a dc voltage source, a finite non-zero current is observed to flow through the element. The element is a/an
- Resistance
 - Inductance
 - Capacitance
 - Mutual inductance
64. Ideal transformer cannot be described by
- h parameters
 - $ABCD$ parameters
 - G parameters
 - z parameters
65. Ideally, attenuator pads should not change
- Voltage level
 - Impedance level
 - Power level
 - Voltage power or impedance levels
66. The design of electric wave filter is based on its characteristic impedance, which at all frequencies is a
- Pure resistance
 - Pure reactance
 - Pure resistance in the pass band and pure reactance in stop band
 - Pure reactance in the pass band and pure resistance in the stop band
67. In active filter circuits, inductance are avoided mainly because they
- Are always associated with some resistance
 - Are bulky and unsuitable for miniaturization
 - Are non-linear in nature
 - Saturate quickly
68. The magnitude response of a normalized butter worth low-pass filter is
- Linear starting with the values of unity at zero frequency and 0.707 at the cut-off frequency
 - Non-linear all through but with values of unity at zero frequency and 0.707 at the cut-off frequency
 - Linear upto the cut-off frequency and non linear thereafter
 - Non-linear up to the cut-off frequency and linear thereafter
69. Which of the following pairs are correctly matched?
- Brune's realization Realization with ideal transformer
 - Cauer realization Ladder realization
 - Bott-Duffin realization Realization with non-ideal transformer
- Select the correct answer using the codes given below:
- Codes:
- 1, 2 and 3
 - 2 and 3
 - 1 and 3
 - 1 and 2
70. The poles and zeros of a driving-point function of a network are simple and interlace on the negative real axis with a pole closest to the origin. It can be realized
- By an LC network
 - As an RC driving-point impedance
 - As an RC driving-point admittance
 - Only by an RLC network
71. The transfer function, $T(s) = \frac{s}{s+a}$ is that of a
- Low pass filter
 - Notch filter
 - High pass filter
 - Band pass filter
72. Voltage transfer function of a simple RC integrator has
- A finite zero and a pole at infinity
 - A finite zero and a pole at the origin
 - A zero at the origin and a finite pole
 - A zero at infinity and a finite pole
73. If two identical first order low-pass filters are cascaded non-interactively, then the unit step response of the composite filter will be
- Critically damped
 - Under damped
 - Over damped
 - Oscillatory
74. Poles and zeros of a driving-point function of network are simple and interlaced on the $j\omega$ axis. The network consists of elements
- R and C
 - L and C
 - R and L
 - R , L and C
75. The locus of the tip of the voltage phasors (V_R) across the resistance (R) in a series RLC resonant circuit is given by Consider the following statements:
- An iron-cored choke is a nonlinear and passive
 - A carbon resistor kept in sunlight is a time-invariant and passive device
 - A dry cell is time-varying and active device
 - An air capacitor is a time varying and passive device
- Of these statements:
- 1, 2, 3 and 4 are correct
 - 1, 2, 3 and 3 are correct
 - 1, 2 and 4 and correct
 - 2 and 4 are correct
76. In a series RLC high Q circuit, the current peaks at a frequency
- Equal to the resonant frequency
 - Greater than the resonant frequency
 - Less than the resonant frequency
 - None of the above is true
77. Two port networks are connected in cascade. The parameters of the network are obtained by multiplying the individual
- z -parameter matrix
 - h -parameter matrix
 - y -parameter matrix
 - $ABCD$ parameter matrix
78. The necessary and sufficient condition for a rational function of $T(s)$ to be driving point impedance of an RC network is that all poles and zero should be
- Simple and lie on the negative axis in the s -plane
 - Complex and lie in the left of the s -plane
 - Complex and lie in the right of the s -plane
 - Simple and lie on the positive real axis of the s -plane

4.22 ■ Network Theory

79. A network contains linear resistors and ideal voltage sources. If values of all the resistors are doubled, then the voltage across each resistor is
 - (a) halved
 - (b) doubled
 - (c) increased by four times
 - (d) not changed
80. Relative to a given fixed tree of a network
 - (a) Link currents form an independent set
 - (b) Branch current an independent set
 - (c) Link voltage form an independent set
 - (d) Branch voltage form an independent set
81. A DC voltage source is connected across a series R-L-C circuit. Under steady-state conditions, the applied DC voltage drops entirely across the
 - (a) R only
 - (b) L only
 - (c) C only
 - (d) R and L combination
82. The nodal method of circuit analysis is based on
 - (a) KVL and Ohm's law
 - (b) KCL and Ohm's law
 - (c) KCL and KVL
 - (d) CL, KVL and Ohm's law
83. Superposition theorem is not applicable to networks containing
 - (a) Non-linear elements
 - (b) Dependent voltage sources
 - (c) Dependent current source
 - (d) Transformers
84. The first and the last critical frequency of an RC-driving point impedance function must respectively be
 - (a) A zero and a pole
 - (b) A zero and a zero
 - (c) A pole and a pole
 - (d) A pole and a zero
85. The first and the last critical frequencies (singularities) of a driving point impedance function of a passive network having two kinds of elements, are a pole and a zero respectively. The above property will be satisfied by
 - (a) RL network only
 - (b) RC network only
 - (c) LC network only
 - (d) RC as well as RL networks
86. Two coils having equal resistance but different inductances are connected in series. The time-constant of the series combination is
 - (a) sum of the time constants of the individual coils
 - (b) average of the time constant of the individual coils
 - (c) geometric mean of the time-constants of the individual coils
 - (d) product of the time-constants of the individual coils
87. An ideal voltage source will charge the ideal capacitor
 - (a) Infinite time
 - (b) Exponentially
 - (c) Instantaneously
 - (d) None of the above
88. A practical current source is usually represented by
 - (a) A resistance in series with an ideal current source
 - (b) A resistance in parallel with ideal current source
 - (c) a resistance in parallel with an ideal voltage source
 - (d) None of the above
89. In a uniform electric field, lines and equipotentials
 - (a) Are parallel to one another
 - (b) Intersect at 45°
 - (c) Intersect at 30°
 - (d) are orthogonal
90. Energy stored in a capacitor over a cycle, when excited by an a.c. source is
 - (a) The same as that due to a dc source of equivalent magnitude
 - (b) Half of the due to a dc source or equivalent magnitude
 - (c) Zero
 - (d) None of the above
91. A major advantage of active filters is that they can be realized without using
 - (a) op-amps
 - (b) inductors
 - (c) resistors
 - (d) capacitors
92. In a series RLC circuit at resonance, the magnitude of the voltage developed across the capacitor
 - (a) Is always zero
 - (b) Can never be greater than the input voltage
 - (c) Can be greater than the input voltage however, it is 90° out of phase with input voltage
 - (d) Can be greater than the input voltage, and is in phase with the input voltage
93. A passive 2-port network is in a steady-state. Compared to its input, the steady state output can never offer
 - (a) higher voltage
 - (b) lower impedance
 - (c) greater power
 - (d) better regulation
94. The transfer function of a passive circuit has is poles and zeroes on
 - (a) Left and right halves respectively of the s -plane
 - (b) Right and left halves respectively of the s -plane
 - (c) Right half of the s -plane
 - (d) left half of the s -plane
95. Superposition theorem does not hold for
 - (a) R-L-C networks
 - (b) Networks containing diodes and R-C elements
 - (c) Linear op-amp circuit
 - (d) None of the above
96. The driving point impedance function $Z(s) = \frac{s^2 + 2s + 2}{s^2 + s + 1}$ can be realized as a
 - (a) R-C network
 - (b) R-L network
 - (c) L-C network
 - (d) R-L-C network
97. A series R-L-C circuit, excited by a 100V variable frequency sources, has a resistance of 10Ω and an inductive reactance of 50Ω at 100 Hz. If the resonance frequency is 500 Hz, what is the voltage across the capacitor at resonance?
 - (a) 100 V
 - (b) 500 V
 - (c) 2500 V
 - (d) 5000 V

98. What is the transfer function of a system whose impulse response is $e^{-3t} \sin 2t$?

- (a) $\frac{13}{s^2 + 6s + 13}$ (b) $\frac{1}{s^2 + 6s + 13}$
 (c) $\frac{2}{s^2 + 6s + 13}$ (d) $\frac{5}{s^2 + 6s + 13}$

99. The system function $H(s) = \frac{1}{s+1}$. For input signal $\cos t$, the steady state response is

- (a) $\frac{1}{\sqrt{2}} \cos \left(t - \frac{\pi}{4} \right)$ (b) $\cos t$
 (c) $\cos \left(t - \frac{\pi}{4} \right)$ (d) $\frac{1}{\sqrt{2}} \cos t$

100. The transfer function $\frac{V_2(s)}{V_1(s)} = \frac{10s}{s^2 + 10s + 100}$ is for an active

- (a) low pass filter (b) band pass filter
 (c) high pass filter (d) all pass filter

LEVEL 2

1. The condensers of $20 \mu F$ and $40 \mu F$ capacitance are connected in series across a 90 V supply. After charging, they are removed from the supply and are connected in parallel with positive terminals connected together and similarly the negative terminals. Then the voltage across them will be

(a) 90 V (b) 60 V
 (c) 40 V (d) 20 V

2. In a two-port network, the condition for reciprocity in terms of 'h' -parameters is

- (a) $h_{12} = h_{21}$ (b) $h_{11} = h_{22}$
 (c) $h_{11} = -h_{22}$ (d) $h_{12} = -h_{21}$

3. The power delivered to a three-phase load can be measured by the use of two wattmeter only when the

- (a) Load is balanced
 (b) Three-phase load is connected to the source through three wires
 (c) Load is unbalanced
 (d) Three-phase load is connected to the source through four wires

4. A three-phase star-connected symmetrical load consumes P watts of power from a balanced supply. If the same load is connected in delta to the same supply, the power consumption will be

- (a) p
 (b) $\sqrt{3} p$
 (c) $3 p$
 (d) not determinable from the given data

5. An input $f(t)$ is applied to a linear network giving a response $g(t)$. The function $f(t)$ is delayed by 1 time unit. If the network is time-invariant, then response will be

- (a) $g(t)$ (b) $g(t-1)$
 (c) $g'(t)$ (d) $1-g(t)$

6. The coupling between two magnetically coupled coils is said to be ideal if the coefficient of coupling is

- (a) zero (b) 0.5
 (c) 1 (d) 2

7. A series RLC circuit, consisting of $R = 10$ ohms, $X_L = 20$ ohms and $X_C = 20$ ohms is connected across an ac supply of 100 V (rms). The magnitude and phase angle (with reference to supply voltage) of the voltage across the inductive coil are respectively

- (a) 100 V; 90° (b) 100 V; -90°
 (c) 200 V; -90° (d) 200 V; 90°

8. An alternator is delivering power to a balanced load at unit power factor. The phase angle between the line voltage and the line current is

- (a) 90° (b) 60°
 (c) 30° (d) 0°

9. A 10 V battery with an internal resistance of 1Ω is connected across a non-linear load whose $v-i$ characteristic is given by $7i = v^2 + 2v$. The current delivered by the battery is

- (a) 2.5 A (b) 5 A
 (c) 6 A (d) 7 A

10. For a two-port network to be reciprocal, it is necessary that

- (a) $z_{11} = z_{22}$ and $y_{21} = y_{12}$
 (b) $z_{11} = z_{22}$ and $AD - BC = 0$
 (c) $h_{21} = h_{12}$ and $AD - BC = 0$
 (d) $y_{21} = y_{12}$ and $h_{21} = -h_{12}$

11. An initially relaxed RC-series network with $R = 2 M\Omega$ and $C = 1 \mu F$ is a switched on to a 10 V step input. The voltage across the capacitor after 2 seconds will be

- (a) zero (b) 3.68 V
 (c) 6.32 V (d) 10 V

12. An initially relaxed 100 mH inductor is switched 'ON' at $t = 1$ sec, to an ideal 2 A dc current source. The voltage across the inductor would be

- (a) zero (b) $0.2 \delta(t)$ V
 (c) $0.2 \delta(t-1)$ V (d) $0.2 t u(t-1)$ V

13. The current through the current coil of a wattmeter is given by, $i = (1 + 2 \sin \omega t)$ V and the voltage across the pressure coil is, $v = (2 + 3 \sin 2\omega t)$ A. The wattmeter will read

- (a) 8.00 W (b) 5.05
 (c) 2.0 W (d) 1.0 W

14. An RLC resonant circuit has a resonance frequency of 1.5 MHz and a bandwidth of 10 kHz. If $C = 150$ pF, then the effective resistance of the circuit will be

- (a) 29.5Ω (b) 14.75Ω
 (c) 9.4Ω (d) 4.7Ω

15. A three-phase, three-wire supply feeds a load consisting of three equal resistors connected in star. If one of the resistors is open circuited, then the percentage reeducation in the load will be

- (a) 75 (b) 66.66
 (c) 50 (d) 3.33

16. Two identical coils of negligible resistance, when connected in series across a 50 Hz fixed voltage source, draw a current of 10 A. When the terminals of the coils are reversed, the current drawn is 8 A. The coefficient of coupling between the two coils is
 (a) 1/100 (b) 1/9
 (c) 4/10 (d) 8/10
17. Five cells are connected in series in a row and then four rows are connected in parallel to feed the current to a resistive load of 1.25 W. Each cell has emf of 15 V with internal resistance of 0.2 W. The current through the load will be
 (a) 3.33 A (b) 23.33 A
 (c) 5 A (d) 1 A
18. The mutual inductance between two coupled coils is 10 mH. If the turns in one coil are doubled and that in the other are halved, then the mutual inductance will be
 (a) 5 mH (b) 10 mH
 (c) 14 mH (d) 20 mH
19. Four resistance 80 Ω , 50 Ω , 25 Ω and R are connected in parallel. Current through 25 Ω resistance is 4 A. Total current of the supply is 10 A. The value of R will be
 (a) 66.66 Ω (b) 40.25 Ω
 (c) 36.36 Ω (d) 76.56 Ω
20. A function $f(t) = \sin 1.1t + \sin 3.3t$ has the time period of
 (a) $\frac{\pi}{1.1}$ (b) $\frac{2\pi}{1.1}$
 (c) $\frac{2\pi}{3.3}$ (d) $\frac{2\pi}{2.2}$
21. A three-phase heating unit and induction motor are connected in parallel across a 208 V three-phase supply. Motor is rated at 5hp, 0.8 pf with efficiency of 0.85. Heating unit is rated at 1500 W. The line current will be equal to
 (a) 185 A (b) 1.85 A
 (c) 18.5 A (d) 15 A
22. A 10 μF capacitor is fed from an ac voltage source containing a fundamental and a third harmonic of value one-third of fundamental. The third harmonic current flowing through the capacitor expressed as percentage of the fundamental under steady-state condition will be
 (a) zero (b) 100
 (c) 30 (d) 90
23. A voltage $v(t) = 6 e^{-2t}$ is applied to $t = 0$ to a series R-L circuit with $L = 1$ H. If $i(t) = 6 [\exp(-2t) - \exp(-3t)]$ then R will have a value of
 (a) 2/3 Ω (b) 1 Ω
 (c) 3 Ω (d) 1/3 Ω
24. An ac source of 200 V rms supplies active power of 600 W and reactive power of 800 VAR. The rms current drawn from the source is
 (a) 10 A (b) 5 A
 (c) 3.75 A (d) 2.5 A
25. For a series RLC circuit, the power factor at the lower power frequency is
 (a) 0.5 lagging (b) 0.5 leading
 (c) Unity (d) 0.707 leading
26. In the circuit shown in the above figure, the voltage across the 2 ohm resistor is
 (a) 6 V (b) 4V
 (c) 2 V (d) zero
27. At a certain current, the energy stored in an iron-cored coil is 1000 J and its copper is 2000 W. The time constant (in seconds) of the coil is
 (a) 0.25 (b) 0.5
 (c) 1.0 (d) 2.0
28. If an R-L circuit having impedance angle ϕ is switched on when figure under sinusoidal voltage wave is passing trough and angle θ , there will be no switching transition if
 (a) $\theta - \phi = 0$ (b) $\theta + \phi = 0$
 (c) $\theta - \phi = 90^\circ$ (d) $\theta + \phi = 90^\circ$
29. A coil having a resistance of 5 ohms and inductance of 0.1H connected in series with a condenser of capacitance 50 μF . A constant alternating voltage of 200 volts is applied to the circuit. The voltage across the coil at resonance is
 (a) 200 volts (b) 1788 volts
 (c) 1800 volts (d) 2000 volts
30. Two coupled coils connected in series have an equivalent inductance of 16 mH or 8 mH depending on the inter-connection. Then the mutual inductance M between the coils is
 (a) 12 mH (b) $8\sqrt{2}$ mH
 (c) 4 mH (d) 2 mH
31. Two coupled coils with $L_1 = L_2 = 0.6$ H have a coupling coefficient of $K = 0.8$. The turns ratio $\frac{N_1}{N_2}$ is
 (a) 4 (b) 2
 (c) 1 (d) 0.5
32. An RLC series circuit has f_1 and f_2 half power frequencies and f_o as the resonance frequency. The Q-factor of the circuit is given by
 (a) $\frac{f_1 + f_2}{2f_o}$ (b) $\frac{f_1 - f_o}{f_2 - f_o}$
 (c) $\frac{f_o}{f_1 - f_2}$ (d) $\frac{f_2 + f_1}{f_o}$
33. The number of turns of a coil having a time constant T are doubled. Then the new time constant will be
 (a) T (b) 2T
 (c) 4T (d) T/2
34. An alternating current source having voltage $E = 110 \sin(\omega t + \pi/3)$ is connected in an ac circuit. The current drawn from the circuit varies as $I = 5 \sin(\omega t - \pi/3)$, the impedance of the circuit will be
 (a) 22 Ω (b) 16 Ω
 (c) 30.8 Ω (d) None of the above
35. The energy required to change the speed of an electron from rest to 0.6c is nearly
 (a) 0.085 Me V (b) 0.13Me V
 (c) 0.29 Me V (d) 0.37Me V

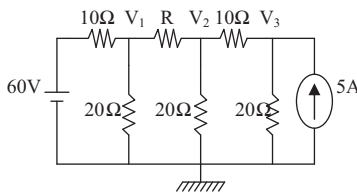
36. In a two-terminal network, the open-circuit voltage is measured at the given terminals by an electronic voltmeter is 100 V. A short-circuit current measured at the same terminals by an ammeter of negligible resistance is 5 A. If a load resistor of 80Ω is connected at the same terminals, then the current in the load resistance will be

(a) 1 A (b) 1.25 A
(c) 6 A (d) 6.25 A

37. The network has 10 nodes and 17 branches. The number of different node pair voltage would be

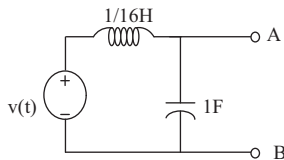
(a) 7 (b) 9
(c) 10 (d) 45

38. In the below circuit, $V_1 = 40$ V when R is 10Ω , when R is zero, the value of V_2 will be



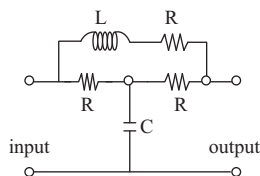
(a) 40 V (b) 30 V
(c) 20 V (d) 10 V

39. The circuit shown in the figure, will act as an ideal current source with respect to terminals A and B, when frequency is



(a) zero (b) 1 rad/s
(c) 4 rad/s (d) 16 rad/s

40. The circuit shown in the figure is a



(a) low pass filter (b) high pass filter
(c) band pass filter (d) band stop filter

41. A series LCR circuit with $R = 10\Omega$, $|X_L| = 20\Omega$, and $|X_C| = 20\Omega$ is connected across an ac supply of 200 V rms. The rms voltage across the capacitor is

(a) $200 \angle -90^\circ$ V (b) $200 \angle 90^\circ$ V
(c) $400 \angle 90^\circ$ V (d) $400 \angle -90^\circ$ V

42. A unit step current is applied to a network consisting of only passive elements. The voltage across the current source

observed is $v(t) = (1 + e^{-t/\tau})$. The simplest possible network will consist of the elements

(a) 1 resistor and 2 capacitors
(b) 1 resistor and 2 inductors
(c) 2 resistor and 1 capacitor
(d) 2 resistor and 1 inductor

43. If R , L , C and G are the resistance, inductance, capacitance and conductance of a transmission line respectively, then the condition for distortion less transmission line is

(a) $R/C = GL$ (b) $RC = LG$
(c) $R^2C = G^2L$ (d) $RC^2 = GL^2$

44. A series RL circuit is initially relaxed. A step voltage is applied to the circuit. If τ is the time constant of the circuit, the voltage across R and L will be the same at time t equal to

(a) $\tau \ln 2$ (b) $\tau \ln \left(\frac{1}{2}\right)$
(c) $\frac{1}{\tau \ln 2}$ (d) $\frac{1}{\tau \ln \left(\frac{1}{2}\right)}$

45. The inverse Fourier transform of $\delta(f)$ is

(a) $u(t)$ (b) 1
(c) $\delta(t)$ (d) $e^{j2\pi t}$

46. A discrete LTI system is non causal if its impulse response is

(a) $a^n u(n-2)$ (b) $a^{n-2} u(n-2)$
(c) $a^{n+2} u(n)$ (d) $a^n u(n+2)$

47. The number of edges in a complete graph of n vertices is

(a) $n(n-1)$ (b) $n(n-1)/2$
(c) $0.5A$ (d) $n-1$

48. A two port network is reciprocal, if and only if

(a) $Z_{11} = Z_{22}$ (b) $BC - AD = -1$
(c) $Y_{12} = -Y_{21}$ (d) $h_{12} = h_{21}$

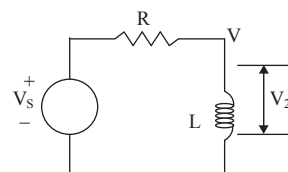
49. For an ideal step-down ($n : 1$) transformer, Which one of the following is the $ABCD$ parameter matrix?

(a) $\begin{pmatrix} n & 1 \\ 1 & n \end{pmatrix}$ (b) $\begin{pmatrix} n & 0 \\ 0 & n \end{pmatrix}$
(c) $\begin{pmatrix} n & 0 \\ 0 & 1/n \end{pmatrix}$ (d) $\begin{pmatrix} n & 1/n \\ 1/n & 1 \end{pmatrix}$

50. If a unit step current is passed through a capacitor what will be the voltage across the capacitor?

(a) 0 (b) A step function
(c) A ramp function (d) An impulse function

51. In the circuit shown, $V_s = 250 \sin 400t$, $|V_2| = 200$. If $R = 100$, value of L is



4.26 ■ Network Theory

- (a) 1/3 (b) 1/4
(c) 2/3 (d) 3/4
52. A real transformer has primary self-inductance $L_1 = 9\text{ H}$ and secondary self inductance $L_2 = 4\text{ H}$ and a mutual inductance between the primary and secondary $M = 3\text{ H}$. The primary and secondary leakage inductance of the transformer are
(a) (3, 6) (b) (6, 1)
(c) (7, 22) (d) (4.5, 2)
53. A 24 V battery of internal resistance $r = 4\text{ ohm}$ is connected to a variable resistance R . The rate of heat dissipation in the resistor is maximum when the current drawn from the battery is I . Current drawn from the battery will be $I/2$, when R is equal to
(a) 8 ohms (b) 12 ohms
(c) 16 ohms (d) 20 ohms
54. A circuit which resonates at 1 MHz has a Q of 100. Bandwidth between half-power points is
(a) 10 kHz (b) 100 kHz
(c) 10 kHz (d) 100 kHz
55. A series RLC circuit is over damped when
(a) $\frac{R^2}{4L^2} > \frac{1}{LC}$ (b) $\frac{R^2}{4L^2} = \frac{1}{LC}$
(c) $\frac{R^2}{4L^2} < \frac{1}{LC}$ (d) $R = \text{infinity}$
56. Consider the following functions:
1. $\frac{s^3 + 3s}{2(s^2 + 1)}$ 2. $\frac{s^2 + 3s + 1}{5(s^2 + 1)}$
3. $\frac{s^2 + 1}{3s}$ 4. $\frac{3\left(s^3 + \frac{7s}{2}\right)}{s^4 + 14s^2 + 30}$
Which of these are valid driving-point impedance function?
(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 2, 3 and 4
57. Consider the following driving-point functions:
 $F_1 = \frac{(s^2 + 1)(s^2 + 3)}{s(s^2 + 4)}$, $F_2 = \frac{(s^2 + 1)(s^2 + 3)}{(s^2 + 2)(s^2 + 4)}$
 $F_3 = \frac{s(s^2 + 3)}{(s^2 + 2)(s^2 + 4)}$ and $F_4 = \frac{(s^2 + 2)(s^2 + 5)}{s(s^2 + 4)}$
Among these, the LC function would include
(a) F_1 and F_2 (b) F_2 and F_3
(c) F_3 and F_4 (d) F_1 and F_4
58. A driving-point impedance function is given by
$$F = \frac{(s + k_1)(s + k_2)(s + k_3)}{(s + 1)(s + 2)(s + 3)(s + 4)}$$

The product $k_1 k_2 k_3$ cannot be more than
(a) 48 (b) 24
(c) 10 (d) 4
59. The Laplace transform of the filament $f(t)$ is $F(s)$. $u(t)$ represents the unit step function. The inverse Laplace transform is
(a) $f(t)u(t-1)$ (b) $f(t-1)u(t)$
(c) $f(t-1)u(t-1)$ (d) $\frac{f(t)}{(t-1)}$
60. If the unilateral Laplace transform $X(s)$ of a signal $x(t)$ is $\frac{7s+10}{s(s+2)}$, then the initial and final values of the signal would be respectively
(a) 3.5 and 5 (b) zero and 7
(c) 5 and zero (d) 7 and 5
61. In an amplifier, the increase in gain is 12 dB if the frequency is doubled. If the frequency is increased by 10 times, then the increase in gain will be
(a) 2.4 dB (b) 20 dB
(c) 40 dB (d) 60 dB
62. For a second order system, if both the roots of the characteristic equation are real, then the value of damping ratio will be
(a) less than unity (b) equal to unity
(c) equal to zero (d) greater than unity
63. If the number of branches in a network is 'B', the number of nodes is 'N' and the number of dependent loops is 'L', then the number of independent node equations will be
(a) $N + L - 1$ (b) $B - 1$
(c) $B - N$ (d) $N - 1$
64. A resistance of 'R' Ω and inductance of 'L' H are connected across 240 V, 50 Hz supply. Power dissipated in the circuit is 300 W and the voltage across R is 100V. In order to improve the power factor to unity, the capacitor that is to be connected in series should have a value of
(a) 43.7 μF (b) 4.37 μF
(c) 437 μF (d) 4.37 mF
65. For a two-port symmetrical bilateral network, if $A = 3$ and $B = 1\text{ }\Omega$, the value of parameter C will be
(a) 4 s (b) 6 s
(c) 8 s (d) 16 s
66. An electric circuit with ten branches and seven nodes will have
(a) 3 loop equations (b) 4 loop equations
(c) 7 loop equations (d) 10 loop equations
67. The response i of a network is expressed by the differential equation $\frac{d^2 i}{dt^2} + i = v$. If $v = Ae^{2t}$, the dominant solution of i for $t > 0$ is of the nature
(a) $K_1 e^t$ (b) $K_1 e^{-t}$
(c) $K_1 e^{2t}$ (d) $K_2 \cos t + K_3 \sin t$
68. The response of an initially relaxed system to a unit ramp excitation is $(t + e^{-t})$. Its step response will be
(a) $\frac{1}{2}t^2 - e^{-t}$ (b) $1 - e^{-t}$
(c) $-e^{-t}$ (d) t

69. The response of a network is $i(t) = K t e^{-\alpha t}$ for $t \geq 0$ where, α is real positive. The value of ' t ' at which the $i(t)$ will become maximum, is
 (a) α (b) 2α
 (c) $\frac{1}{\alpha}$ (d) α^2
70. The h parameters h_{11} and h_{22} are related to z and y parameters as
 (a) $h_{11} = z_{11}$ and $h_{22} = 1/z_{22}$
 (b) $h_{11} = z_{11}$ and $h_{22} = y_{22}$
 (c) $h_{11} = 1/y_{11}$ and $h_{22} = 1/z_{22}$
 (d) $h_{11} = 1/y_{11}$ and $h_{22} = y_{22}$
71. The driving point impedance $Z(s) = \frac{s+2}{s+3}$. The system is initially at rest. For a voltage signal of unit step the current $i(t)$ through the impedance Z is given by
 (a) $2 - e^{-t}$ (b) $\frac{3}{2} - \frac{1}{2}e^{-3t}$
 (c) $\frac{3}{2} - \frac{1}{2}e^{-2t}$ (d) $3 - 2e^{-2t}$
72. If the combined generator and line Impedance is $(5 + j10)$ ohm, then for the maximum power transfered to a load impedance from a generator of constant generated voltage, the load impedance is given by which one of the following?
 (a) $(5 + j10)\Omega$ (b) $(5 - j10)\Omega$
 (c) $(5 + j5)\Omega$ (d) 5Ω
73. The impulse response of an LTI system is given by $5u(t)$. If the input to the system is given by e^{-t} then the output of the system is given by
 (a) $5(1 - e^{-t})u(t)$ (b) $(1 - 5e^{-t})u(t)$
 (c) $5 - e^{-t}u(t)$ (d) $5u(t) - e^{-t}$
74. A parallel circuit consists of two branches. One branch has R_L and L connected in series and the other branch has R_C and C connected in series. Consider the following statements:
 1. The two branch currents will be in quadrature if $R_L R_C = L/C$
 2. The impedance of the whole circuit is independent of frequency, if $R_L = R_C$ and $\omega = \frac{1}{\sqrt{LC}}$
 3. The circuit is in resonance for all the frequencies if $R_L = R_C$
 4. The two branch currents will be in phase at $\omega = \frac{1}{\sqrt{LC}}$
 Which of the above statements are correct?
 (a) 1 and 2 (b) 2 and 3
 (c) 1 and 3 (d) 3 and 4
75. Three currents i_1 , i_2 , and i_3 , are approaching a node. If $i_1 = 10 \sin(400t + 60^\circ)$ A, and $i_2 = 10 \sin(400t - 60^\circ)$ A, the i_3 , is
 (a) 0
 (b) $10(\sin 400t)$ A
 (c) $10(\sin 400t)$ A
 (d) $-5\sqrt{3}(3\sin 400t)$ A
76. The impedance of a parallel RLC network is $Z(s) = \frac{5s}{s^2 + 0.5s + 100}$. Then the values of R , L and C are, respectively
 (a) $10\Omega, \frac{1}{20}H, \frac{1}{5}F$ (b) $1\Omega, \frac{1}{2}H, \frac{1}{5}F$
 (c) $10\Omega, \frac{1}{20}H, \frac{1}{2}F$ (d) $2\Omega, \frac{1}{20}H, \frac{1}{5}F$
77. For a driving point impedance function, $Z(s) = \frac{s+\alpha}{s+\beta}$; the voltage will lead the current for sinusoidal input if
 (a) α and β are real positive and $\alpha > \beta$
 (b) α is real positive and β is real negative and $\alpha > \beta$
 (c) α and β are real positive and $\beta > \alpha$
 (d) α and β are real negative and $\beta > \alpha$
78. A unit step current of $1A$ is applied to a network whose driving impedance is $Z(s) = \frac{V(s)}{I(s)} = \frac{s+3}{(s+2)^2}$; then the steady state and initial values of the voltage developed across the source are respectively
 (a) $\left(\frac{3}{4}V, 1V\right)$ (b) $\left(\frac{1}{4}V, \frac{3}{4}V\right)$
 (c) $\left(\frac{3}{4}V, 0V\right)$ (d) $\left(1V, \frac{3}{4}V\right)$
79. A circuit is modelled by the following differential equation

$$\frac{d^2 i(t)}{dt^2} + \frac{6 di(t)}{dt} + 9 i(t) = 0$$
 The response $i(t)$ is of the form with symbols having their standard meanings
 (a) $K_1 e^{-t} + K_2 e^{-9t}$ (b) $K e^{-3t} \sin(t + \theta)^{-9t}$
 (c) $(K_1 + K_2 t) e^{-3t}$ (d) $K e^{-t} \sin(9t + \theta)$
80. A voltage source having an internal impedance of $8 + j6$ ohms supplies power to a resistive load. What should be the load resistance for maximum power transferred to it?
 (a) 8 ohms (b) 6 ohms
 (c) 10 ohms (d) $\sqrt{10}$ ohms
81. A balanced delta connected load has an impedance of $9 \angle 30^\circ$ ohms per phase. what is the impedance per phase of its equivalent star?
 (a) $27 \angle 30^\circ \Omega$ (b) $27 \angle 90^\circ \Omega$
 (c) $3 \angle 30^\circ \Omega$ (d) $3 \angle 20^\circ \Omega$
82. For a parallel RLC resonant circuit, the damped frequency is $\sqrt{8}$ r/s and bandwidth is 2 r/s. What is its resonant frequency?
 (a) 2 (b) $\sqrt{7}$
 (c) $\sqrt{10}$ (d) 3
83. In an a.c. series RLC circuit, the voltage across R and L is 20 V, voltage across L and C is 9 V and voltage across RLC is 15 V. What is the voltage across C ?
 (a) 7 V (b) 12 V
 (c) 16 V (d) 21 V

84. Two resistors of equal value are connected in series across the lines B and C of a symmetrical three-phase 400 V system. What is the magnitude of the voltage between the line A and the junction of the resistors?

(a) $400/\sqrt{3}$ (b) $200\sqrt{3}$
(c) $400/3$ (d) $100\sqrt{3}$

85. Impedance $Z(s) = [s + 3](s + 5)/[s + 4](s + 6)]$ is realized in the foster's second form. What will be the values, respectively of R and L in one of the series R-L branches?

(a) $2\Omega, \frac{1}{3}H$ (b) $2\Omega, \frac{4}{3}H$
(c) $2\Omega, \frac{5}{3}H$ (d) $2\Omega, \frac{2}{3}H$

86. An R-C series circuit, initially at rest has a step voltage signal. The responses $v(t)$ across C is $v(t) = 1 - e^{-3t}$. If now there is an initial voltage at C of 3 volts, what is $v(t)$ for the same step signal?

(a) $1 + 3e^{-3t}$ (b) $1 + 2e^{-3t}$
(c) $3e^{-3t}$ (d) None of the above

87. In a series R-L-C circuit, the maximum voltage across the capacitor occurs at a frequency
(a) Double the resonant frequency
(b) Equal to resonant frequency
(c) $\sqrt{2}$ times the resonant frequency
(d) Below the resonant frequency

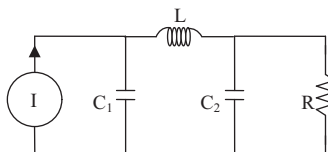
88. Consider the following network functions:

1. $\frac{(s^2 + 1)(s^2 + 4)}{(s^2 + 3)(s^2 + 9)}$ 2. $\frac{(s^2 + 1)(s^2 + 9)}{s(s^2 + 4)}$
3. $\frac{s(s^2 + 9)}{(s^2 + 1)(s^2 + 4)}$ 4. $\frac{s(s^2 + 4)}{(s^2 + 1)}$

Which of the above function can represent L.C driving-Point immittances?

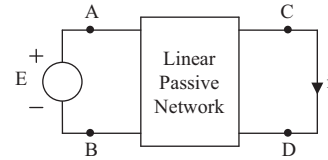
(a) Only 1 and 2
(b) Only 2 and 3
(c) Only 2 and 4
(d) Only 1 and 3

89. For the circuit shown in the given figure, the current through L and the voltage across C_2 are respectively



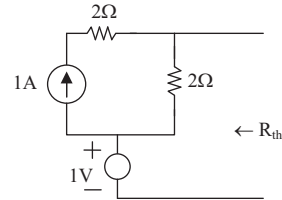
(a) zero and RI (b) 1 and zero
(c) zero and zero (d) I and RI

90. For the circuit shown in the given figure, when the voltage E is 10 V, the current i is 1 A. If the applied voltage across terminal C-D is 100 V, the short circuit current flowing through the terminal A - B will be



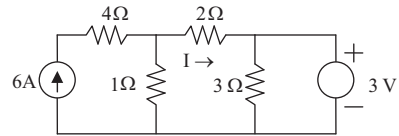
(a) 0.1 A (b) 1 A
(c) 10 A (d) 100 A

91. The Thevenin's equivalent resistance R_{th} for the given network is



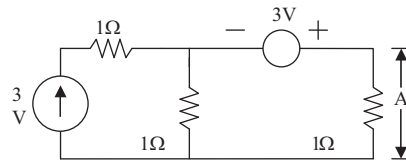
(a) 1 Ω (b) 2 Ω
(c) 4 Ω (d) infinity

92. For the circuit shown in the given figure, the current I is given by



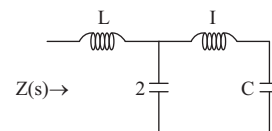
(a) 3 A (b) 2 A
(c) 1 A (d) zero

93. The value of V in the circuit shown in the given figure is



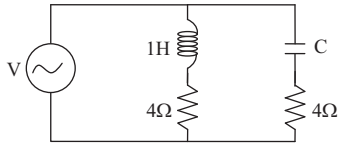
(a) 1 V (b) 2 V
(c) 3 V (d) 4 V

94. For the given driving point impedance function $Z(s) = \frac{4s^4 + 7s^2 + 1}{s(2s^2 + 3)}$, the circuit realization is shown in the given figure. Then the values of L and C are, respectively



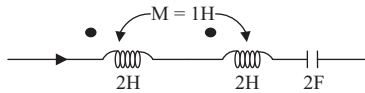
(a) 0.5 and 3 (b) 2 and 1
(c) 4 and 1 (d) 4 and 3

95. The value of the capacitance 'C' in the ac circuit to make it a constant resistance circuit OR for the supply current to be independent of its frequency is



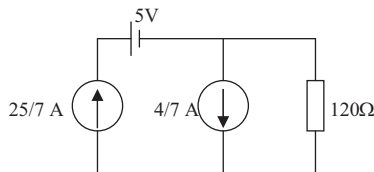
- (a) $\frac{1}{16} F$ (b) $\frac{1}{12} F$
(c) $\frac{1}{8} F$ (d) $\frac{1}{4} F$

96. The resonant frequency of the given series circuit is



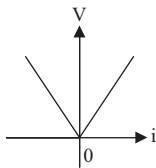
- (a) $\frac{1}{2\pi\sqrt{3}} \text{ Hz}$ (b) $\frac{1}{4\pi\sqrt{3}} \text{ Hz}$
(c) $\frac{1}{4\pi\sqrt{2}} \text{ Hz}$ (d) $\frac{1}{\pi\sqrt{2}} \text{ Hz}$

97. The current through 120 ohm resistor in the circuit shown in the figure is



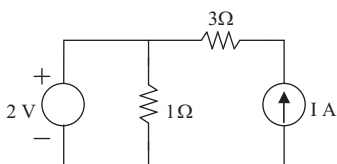
- (a) 1 A (b) 2 A
(c) 3 A (d) 4 A

98. The V-i characteristic of an element is shown in the figure given below. The element is



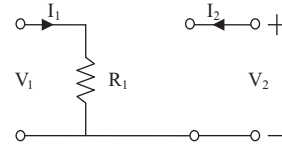
- (a) non-linear, active non-bilateral
(b) linear, active, non-bilateral
(c) non-linear, passive non-bilateral
(d) non-linear, active, bilateral

99. For the circuit given in figure below, the power delivered by the 2 volt source is given by



- (a) 4 W (b) 2 W
(c) -2 W (d) -4 W

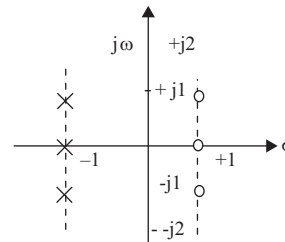
100. The $[Y]$ parameters of the network given in the figure are given by



- (a) $\begin{bmatrix} R_1^{-1} & R_1^{-1} \\ R_1^{-1} & R_1^{-1} \end{bmatrix}$ (b) $\begin{bmatrix} 0 & R_1^{-1} \\ R_1^{-1} & R_1^{-1} \end{bmatrix}$
(c) $\begin{bmatrix} R_1^{-1} & 0 \\ 0 & 0 \end{bmatrix}$ (d) $\begin{bmatrix} R_1^{-1} & 0 \\ R_1^{-1} & 0 \end{bmatrix}$

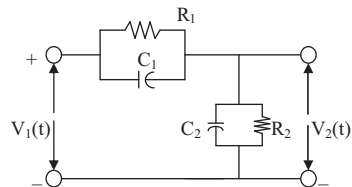
LEVEL 3

1. The pole-zero pattern of a certain filter is shown in the figure below. The filter must be of the following type:



- (a) low-pass (b) high-pass
(c) all-pass (d) band-pass

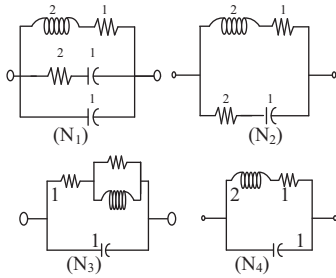
2. For the compensated attenuator of figure, the impulse response under the condition $R_1 C_1 = R_2 C_2$ is



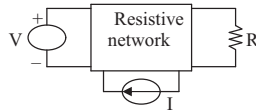
- (a) $\frac{R_2}{R_1 + R_2} [1 - e^{(-1/R_1 C_1)}] u(t)$
(b) $\frac{R_2}{R_1 + R_2} \delta(t)$
(c) $\frac{R_2}{R_1 + R_2} u(t)$
(d) $\frac{R_2}{R_1 + R_2} [1 - e^{(1/R_1 C_1)}] \cdot u(t)$

4.30 ■ Network Theory

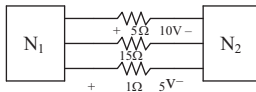
3. Of the four networks, N_1 , N_2 , N_3 and N_4 of the figure the networks having identical driving point function are



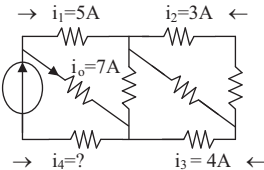
- (a) N_1 and N_2 (b) N_2 and N_4
(c) N_1 and N_3 (d) N_1 and N_4
4. A dc circuit shown in the figure has a voltage source V , a current source I and several resistors. A particular resistor R dissipates a power of 4 Watts when V alone is active. The same resistor R dissipates a power of 9 Watts when I alone is active. The power dissipated by R when both sources are active will be



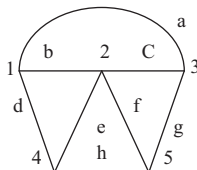
- (a) 1 W (b) 5 W
(c) 13 W (d) 25 W
5. The two electrical sub network N_1 and N_2 are connected through three resistor as shown in the figure. The voltage across 5 ohm resistor and 1 ohm resistor are given to be 10 V and 5 V, respectively. Then voltage across 15 ohm resistor is



- (a) -105 V (b) +105 V
(c) -15 V (d) +15 V
6. The current i_4 in the circuit of the figure is equal to



- (a) 12 A (b) -12 A
(c) 4 A (d) none of the above
7. Identify which of the following is not a tree of the graph shown in the figure

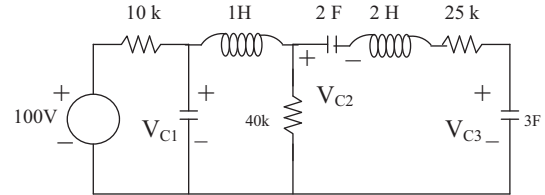


- (a) begb (b) defg
(c) adfg (d) adgh

8. A 2-port network is shown in the figure. The h_{21} for the this network can be given by

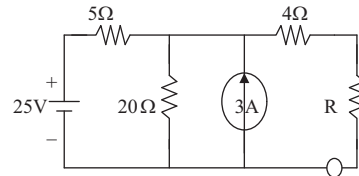
- (a) $-1/2'$ (b) $+1/2$
(c) $-3/2$ (d) $+3/2$

9. The Thevenin equivalent voltage V_{TH} appearing between the terminals A and B of the network shown in the figure is given by



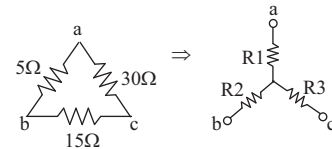
- (a) $j16(3-j4)$ (b) $j16(3+j4)$
(c) $16(3+j4)$ (d) $16(3-j4)$

10. The value of R (in ohms) required for maximum power transfer in the network shown in the figure is



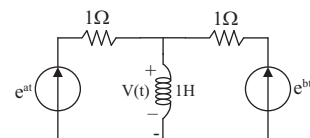
- (a) 2 (b) 4
(c) 8 (d) 16

11. A Delta-connected network with its Wye-equivalent is shown in the figure. The resistances R_1 , R_2 , and R_3 (in ohms) are respectively



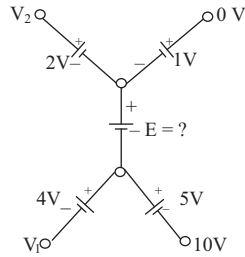
- (a) 1.5, 3 and 9 (b) 3, 9 and 1.5
(c) 9, 3 and 1.5 (d) 3, 1.5 and 9

12. In the circuit of the figure, the voltage $v(t)$ is



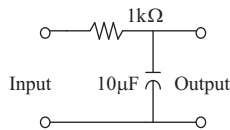
- (a) $e^{at} - e^{bt}$ (b) $e^{at} + e^{bt}$
(c) $ae^{at} - be^{bt}$ (d) $ae^{at} + be^{bt}$

13. In the circuit of the figure, the value of the voltage source E is



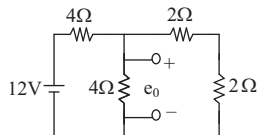
- (a) -16 V (b) 4 V
(c) -6 V (d) 16 V

14. In the figure, the steady state output voltage corresponding to the input voltage $3 + 4 \sin 100t\text{ V}$ is



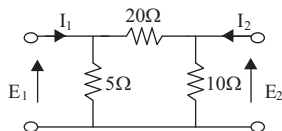
- (a) $3 + (4/\sqrt{2}) \sin(100t - (\pi/4))\text{ V}$
(b) $3 + 4\sqrt{2} \sin(100t - (\pi/4))\text{ V}$
(c) $(3/2) + (4/\sqrt{2}) \sin(100t + (\pi/4))\text{ V}$
(d) $3 + 4 \sin(100t + (\pi/4))\text{ V}$

15. The voltage e_0 in the figure is



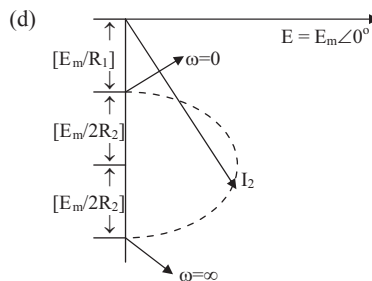
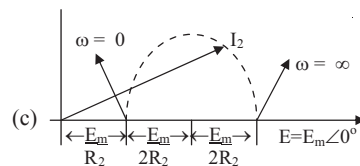
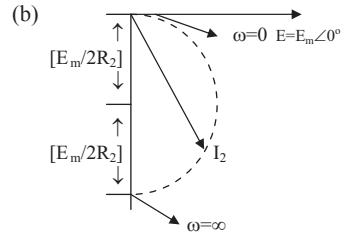
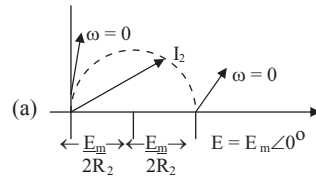
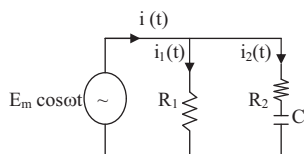
- (a) 2 V (b) $[4/3]\text{ V}$
(c) 4 V (d) 8 V

16. The admittance parameter Y_{12} in the 2-port network in the figure is



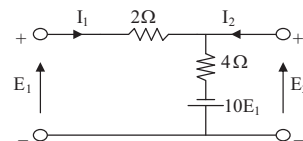
- (a) -0.2 mho (b) 0.1 mho
(c) -0.05 mho (d) 0.05 mho

17. When the angular frequency ω in the figure is varied from 0 to ∞ , the locus of the current phasor I_2 is given by



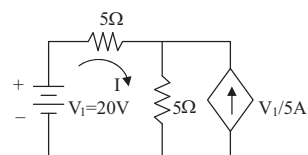
- (a) Figure(a) (b) Figure(b)
(c) Figure(c) (d) Figure(d)

18. The Z parameters Z_{11} and Z_{21} for the 2-port network in the figure are



- (a) $Z_{11} = -[6/11]\Omega$; $Z_{21} = [16/11]\Omega$
(b) $Z_{11} = [6/11]\Omega$; $Z_{21} = [4/11]\Omega$
(c) $Z_{11} = [6/11]\Omega$; $Z_{21} = -[16/11]\Omega$
(d) $Z_{11} = -[4/11]\Omega$; $Z_{21} = [4/11]\Omega$

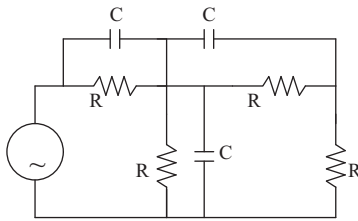
19. The dependent current source shown in the figure



- (a) delivers 80 W (b) absorbs 80 W
(c) delivers 40 W (c) absorbs 40 W

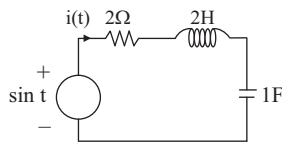
4.32 ■ Network Theory

20. The minimum number of equations required to analyse the circuit shown in the figure



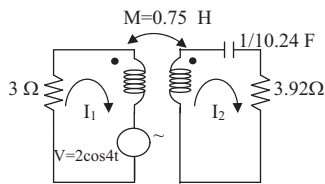
- (a) 3 (b) 4
(c) 6 (d) 7

21. The differential equation for the current $i(t)$ in the circuit of the figure is



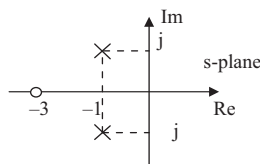
- (a) $2 \frac{d^2 i}{dt^2} + 2 \frac{di}{dt} + i(t) = \sin t$
(b) $2 \frac{d^2 i}{dt^2} + 2 \frac{di}{dt} + i(t) = -\cos t$
(c) $2 \frac{d^2 i}{dt^2} + 2 \frac{di}{dt} + i(t) = \cos t$
(d) $\frac{d^2 i}{dt^2} + 2 \frac{di}{dt} + 2i(t) = \sin t$

22. The current flowing through the resistance R in the circuit in the figure has the form $P \cos 4t$, where, P is



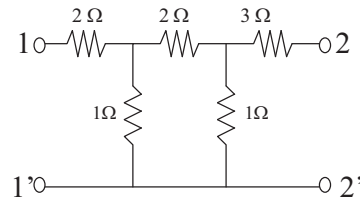
- (a) $(0.18 + j 0.72)$ (b) $(0.46 + j 1.90)$
(c) $-(0.18 + j 1.90)$ (d) $(0.23 - j 0.35) \cos 4t$

23. The driving-point impedance $Z(s)$ of a network has the pole-zero locations as shown in the figure. If $Z(0) = 3$, then $Z(s)$ is



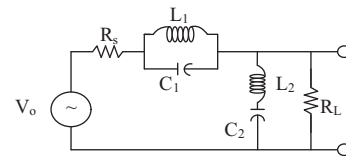
- (a) $\frac{3(s+3)}{s^2 + 2s + 3}$ (b) $\frac{2(s+3)}{s^2 + 2s + 2}$
(c) $\frac{3(s+3)}{s^2 - 2s - 3}$ (d) $\frac{2(s+3)}{s^2 - 2s - 2}$

24. The impedance parameters Z_{11} and Z_{12} of the two-port network in the figure are



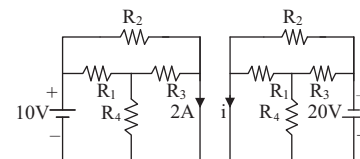
- (a) $Z_{11} = 2.75 \Omega$ and $Z_{12} = 0.25 \Omega$
(b) $Z_{11} = 3 \Omega$ and $Z_{12} = 0.5 \Omega$
(c) $Z_{11} = 3 \Omega$ and $Z_{12} = 0.25 \Omega$
(d) $Z_{11} = 2.25 \Omega$ and $Z_{12} = 0.5 \Omega$

25. The circuit of the figure represents a



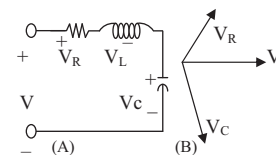
- (a) low pass filter (b) high pass filter
(c) band pass filter (d) band reject filter

26. Use the data of the figure. The current i in the circuit of the figure is



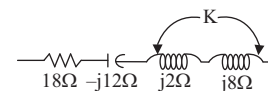
- (a) -2 A (b) 2 A
(c) -4 A (d) 4 A

27. For the series R-L circuit of figure (A), the partial figure diagram at a certain frequency is shown in figure (B). The operating frequency of the circuit is



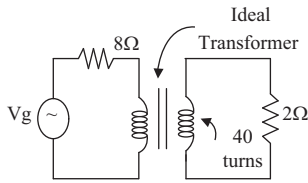
- (a) Equal to the resonance frequency
(b) Less than the resonance frequency
(c) Greater than resonance frequency
(d) Not zero

28. In the series circuit shown in the figure of series resonance, the value of the coupling coefficient K will be

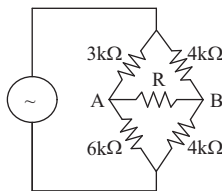


- (a) 0.25 (b) 0.5
(c) 0.999 (d) 1.0

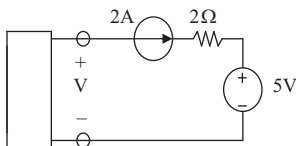
29. If the secondary winding of the ideal transformer shown in the circuit of figure has forty turns, the number of turns in the primary winding for maximum power transfer to the $2\ \Omega$ resistor will be



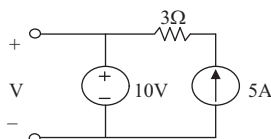
- (a) 20
(b) 40
(c) 80
(d) 160
30. The value of the resistance R , connected across the terminals, A and B , (ref. figure), which will absorb with maximum power, is



- (a) 4.00 k Ω
(b) 4.11 k Ω
(c) 8.00 k Ω
(d) 9.00 k Ω
31. The voltage V in the figure is equal to
-
- (a) 3 V
(b) -3 V
(c) 5 V
(d) none of the above
32. The voltage V in the figure is always equal to

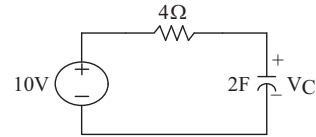


- (a) 9 V
(b) 5 V
(c) 1 V
(d) None of the above
33. The voltage v in the figure is

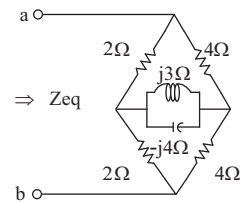


- (a) 10 V
(b) 15 V
(c) 5 V
(d) none of the above

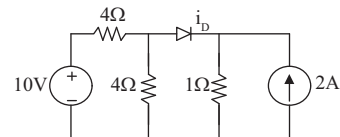
34. In circuit of the figure $V_C(o) = 5\text{ V}$ the energy absorbed by the $4\ \Omega$ resistor in the time interval $(0, \infty)$ is



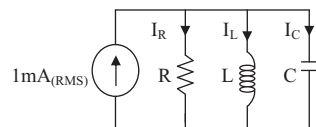
- (a) 36 Joules
(b) 16 Joules
(c) 256 Joules
(d) None of the above
35. In the circuit of the figure, the equivalent impedance seen across terminals a, b is



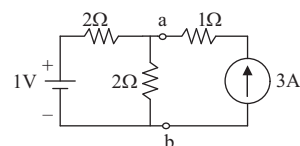
- (a) $(16/3)\ \Omega$
(b) $(8/3)\ \Omega$
(c) $[(8/3) + 12j]\ \Omega$
(d) none of the above
36. In the circuit of the figure, the current i_d through the ideal diode (zero cut in voltage and forward resistance) equals



- (a) 0 A
(b) 4 A
(c) 1 A
(d) none of the above
37. The parallel RLC circuit shown in the figure is in resonance. In this circuit



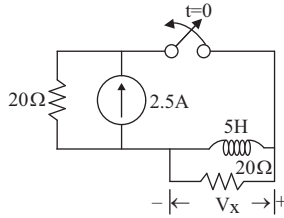
- (a) $|I_R| < 1\text{ mA}$
(b) $|I_R + I_L| > 1\text{ mA}$
(c) $|I_R + I_C| < 1\text{ mA}$
(d) $|I_R + I_C| > 1\text{ mA}$
38. The voltage across the terminals a and b in the figure is



- (a) 0.5 V
(b) 3.0 V
(c) 3.5 V
(d) 4.0 V

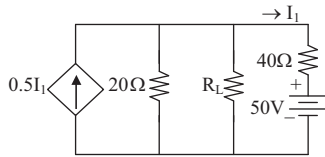
4.34 ■ Network Theory

39. In figure, the switch was closed for a long time before opening at $t = 0$. The voltage V_x at $t = 0^+$ is



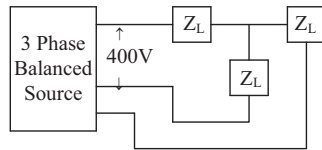
- (a) 25 V
(b) 50 V
(c) -50 V
(d) 0 V

40. In the network of the figure, the maximum power is delivered to R_L if its value is



- (a) 16 Ω
(b) 40/3 Ω
(c) 60 Ω
(d) 20 Ω

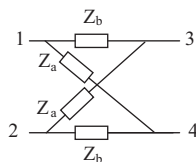
41. If the three-phase balanced source in the figure delivers 1500 W at a leading power factor of 0.844, then the value of Z_L (in ohm) is approximately



- (a) $90 \angle 32.44^\circ$
(b) $80 \angle 32.44^\circ$
(c) $80 \angle -32.44^\circ$
(d) $90 \angle -32.44^\circ$

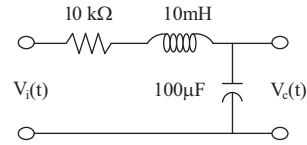
42. For the lattice circuit shown in the figure, $Z_a = j2\Omega$ and $Z_b = 2\Omega$. The values of the open circuit impedance parameters

$$Z = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} \text{ are}$$



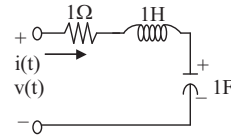
- (a) $\begin{pmatrix} 1-j & 1+j \\ 1+j & 1+j \end{pmatrix}$
(b) $\begin{pmatrix} 1-j & 1+j \\ -1+j & 1-j \end{pmatrix}$
(c) $\begin{pmatrix} 1+j & 1+j \\ 1-j & 1-j \end{pmatrix}$
(d) $\begin{pmatrix} 1+j & -1+j \\ -1+j & 1+j \end{pmatrix}$

43. For the circuit shown in the figure the initial conditions are zero. Its transfer function $H(s) = \frac{V_o(s)}{V_i(s)}$ is



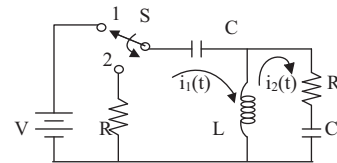
- (a) $\frac{1}{s^2 + 10^6 s + 10^6}$
(b) $\frac{10^6}{s^2 + 10^3 s + 10^6}$
(c) $\frac{10^3}{s^2 + 10^3 s + 10^6}$
(d) $\frac{10^6}{s^2 + 10^6 s + 10^6}$

44. The circuit shown in the figure has initial current $i_L(0^-) = 1$ A through the inductor and an initial voltage $v_C(0^-) = -1$ V across the capacitor. For input $v(t) = u(t)$, the Laplace transform of the current $i(t)$ for $t \geq 0$ is



- (a) $\frac{s}{s^2 + s + 1}$
(b) $\frac{s+2}{s^2 + s + 1}$
(c) $\frac{s-2}{s^2 + s + 1}$
(d) $\frac{s-2}{s^2 + s + 1}$

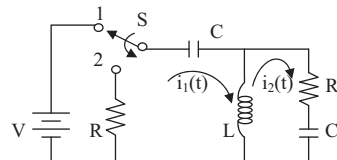
45. Assume that the switch S is in position, for a long time and thrown to position 2 at $t = 0$. At, $t = 0^+$, the current i_1 is



- (a) $(-V/2R)$
(b) $(-V/R)$
(c) $(-V/4R)$
(d) zero

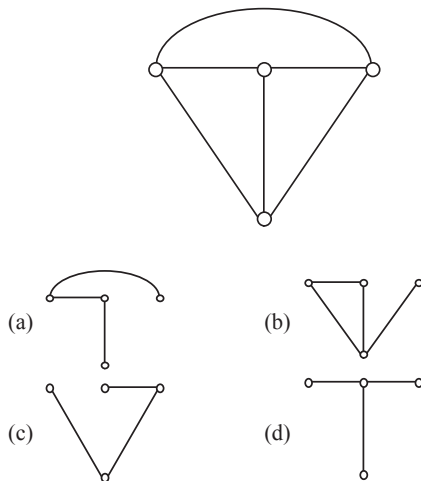
46. Assume that the switch S is in position, for a long time and thrown to position 2 at $t = 0$

$I_1(s)$ and $I_2(s)$ are the Laplace transforms of $i_1(t)$ and $i_2(t)$ respectively. The equations for the loop currents $I_1(s)$ and $I_2(s)$ for the circuit shown in figure (Q. 82) after the switch is brought from position 1 to position 2 at $t = 0$, are

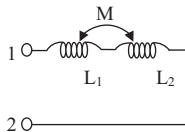


- (a)
$$\begin{pmatrix} R + Ls + \frac{1}{Cs} & -Ls \\ -Ls & R + \frac{1}{Cs} \end{pmatrix} \begin{pmatrix} I_1(s) \\ I_2(s) \end{pmatrix} = \begin{pmatrix} V/s \\ 0 \end{pmatrix}$$
- (b)
$$\begin{pmatrix} R + Ls + \frac{1}{Cs} & -Ls \\ -Ls & R + \frac{1}{Cs} \end{pmatrix} \begin{pmatrix} I_1(s) \\ I_2(s) \end{pmatrix} = \begin{pmatrix} -V/s \\ 0 \end{pmatrix}$$
- (c)
$$\begin{pmatrix} R + Ls + \frac{1}{Cs} & -Ls \\ -Ls & R + Ls + \frac{1}{Cs} \end{pmatrix} \begin{pmatrix} I_1(s) \\ I_2(s) \end{pmatrix} = \begin{pmatrix} -V/s \\ 0 \end{pmatrix}$$
- (d)
$$\begin{pmatrix} R + sL + \frac{1}{Cs} & -Ls \\ -Ls & R + Ls + \frac{1}{Cs} \end{pmatrix} \begin{pmatrix} I_1(s) \\ I_2(s) \end{pmatrix} = \begin{pmatrix} -V/s \\ 0 \end{pmatrix}$$

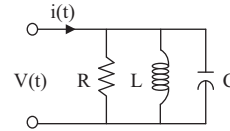
47. Consider the network graph shown in the figure. Which one of the following is not a 'tree' of this graph?



48. The equivalent inductance measured between the terminals 1 and 2 for the circuit shown in the figure is



- (a) $L_1 + L_2 + M$
 (b) $L_1 + L_2 - M$
 (c) $L_1 + L_2 + 2M$
 (d) $L_1 + L_2 - 2M$
49. The circuit shown in the figure with $R = (1/3) \Omega$, $L = (1/4) H$, $C = 3F$ has input voltage $v(t) = \sin 2t$. The resulting current $i(t)$ is

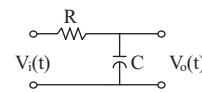


- (a) $5 \sin (2t + 53.1^\circ)$
 (b) $5 \sin (2t - 53.1^\circ)$
 (c) $25 \sin (2t + 53.1^\circ)$
 (d) $25 \sin (2t - 53.1^\circ)$

50. For the circuit shown in the figure, the time constant $RC = 1\text{ms}$. The input voltage is

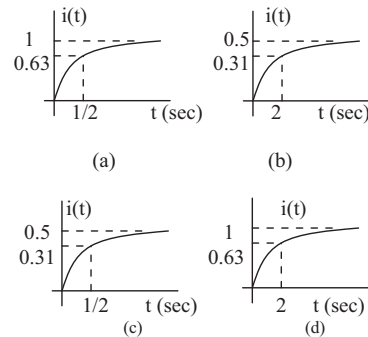
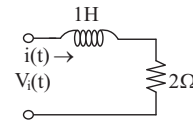
$$V_i(t) = \sqrt{2} \sin 10^3 t$$

The output voltage $v_o(t)$ is equal to



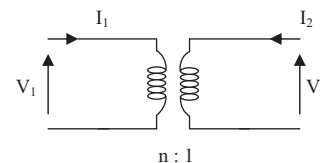
- (a) $\sin (10^3 t - 45^\circ)$ (b) $\sin (10^3 t + 45^\circ)$
 (c) $\sin (10^3 - 53)$ (d) $\sin (10^3 t - 53^\circ)$

51. For the R - L circuit shown in the figure, the input voltage $v_i(t) = u(t)$. The current $i(t)$ is



52. The ABCD parameters of an ideal $n : 1$ transformer shown in the figure are $\begin{pmatrix} n & 0 \\ 0 & X \end{pmatrix}$.

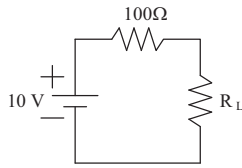
The value of X will be



- (a) n (b) $[1/n]$
 (c) n^2 (d) $[1/n^2]$

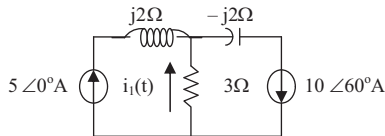
4.36 ■ Network Theory

53. The maximum power that can be transferred to the load resistor R_L from the voltage source shown in the figure is



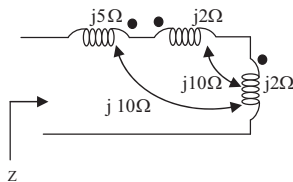
- (a) 1 W (b) 10 W
(c) 0.25 W (d) 0.5 W

54. For the circuit shown in the figure, the instantaneous current $i_1(t)$ is



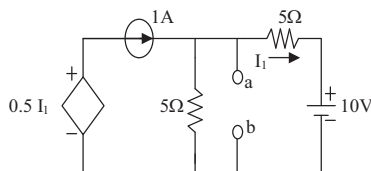
- (a) $[(10\sqrt{3})/2] \angle 90^\circ$ Amps
(b) $[(10\sqrt{3})/2] \angle -90^\circ$ Amps
(c) $5 \angle 60^\circ$ Amps
(d) $5 \angle -60^\circ$ Amps

55. Impedance Z as shown in the given figure is



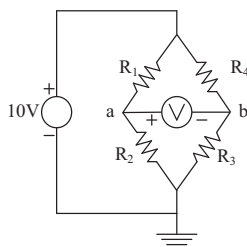
- (a) $j29\Omega$ (b) $j9\Omega$
(c) $j19\Omega$ (d) $j39\Omega$

56. For the circuit shown in the figure, Thevenin's voltage and Thevenin's equivalent resistance at terminals $a-b$ is



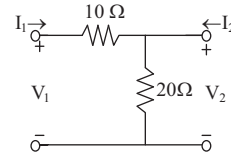
- (a) 5 V and 2Ω (b) 7.5 V and 2.5Ω
(c) 4 V and 2Ω (d) 3 V and 2.5Ω

57. If $R_1 = R_2 = R_4 = R$ and $R_3 = 1.1R$ in the bridge circuit shown in the figure, then the reading in the ideal voltmeter connected between a and b is



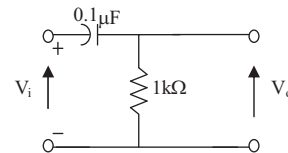
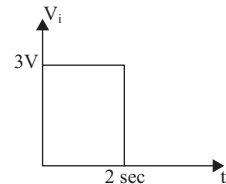
- (a) 0.238 V (b) 0.138 V
(c) -0.238 V (d) 1 V

58. The h parameters of the circuit shown in the figure are



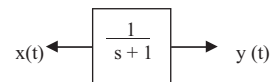
- (a) $\begin{pmatrix} 0.1 & 0.1 \\ -0.1 & 0.3 \end{pmatrix}$ (b) $\begin{pmatrix} 10 & -1 \\ 1 & 0.05 \end{pmatrix}$
(c) $\begin{pmatrix} 30 & 20 \\ 20 & 20 \end{pmatrix}$ (d) $\begin{pmatrix} 10 & 1 \\ -1 & 0.05 \end{pmatrix}$

59. A square of 3 volts amplitude is applied to $C-R$ circuit shown in the figure. The capacitor is initially uncharged. The output V_o at time $t = 2$ sec is



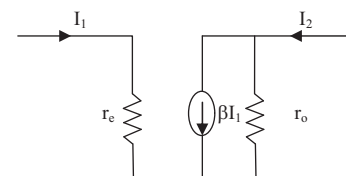
- (a) 3 V (b) -3 V
(c) 4 V (d) -4 V

60. In the system shown below, $x(t) = (\sin t) u(t)$. In steady state, the response $y(t)$ will be



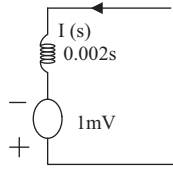
- (a) $(1/\sqrt{2}) \sin [t - (\pi/4)]$ (b) $(1/\sqrt{2}) \sin [t + (\pi/4)]$
(c) $(1/\sqrt{2}) e^{-1} \sin t$ (d) $\sin t - \cos t$

61. In the two port network shown in the figure below, z_{12} and z_{21} are, respectively



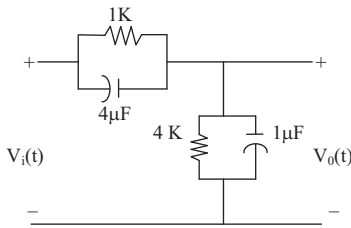
- (a) r_e and βr_o (b) 0 and $-\beta r_o$
(c) 0 and βr_o (d) r_e and $-\beta r_o$

62. A 2 mH inductor with some initial current can be represented as shown below, where s is the Laplace Transform variable. The value of initial current is



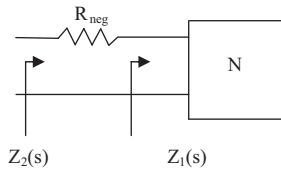
- (a) 0.5 A (b) 2.0 A
(c) 1.0 A (d) 0.0 A

63. In the figure shown in the figure, assume that all the capacitors are initially uncharged. If $v_1(t) = 10 u(t)$ Volts, $V_o(t)$ is given by



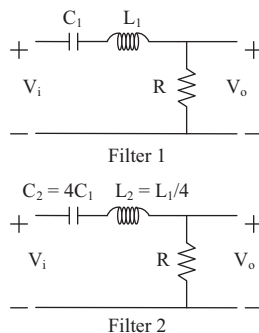
- (a) $8e^{-0.004t}$ Volts (b) $8(1 - e^{-0.004t})$ Volts
(c) $8u(t)$ Volts (d) 8 Volts

64. A negative resistance R_{neg} is connected to a passive network N having driving point impedance $Z_1(s)$ as shown in the figure. For $Z_2(s)$ to be positive real



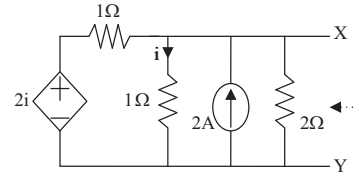
- (a) $|R_{\text{neg}}| \leq \text{Re } Z_1(j\omega), \forall \omega$
(b) $|R_{\text{neg}}| \leq |Z_1(j\omega)|, \forall \omega$
(c) $|R_{\text{neg}}| \leq \text{Im } Z_1(j\omega), \forall \omega$
(d) $|R_{\text{neg}}| \leq \angle Z_1(j\omega), \forall \omega$

65. Two series resonant filter are as shown in the figure. Let the 3-dB bandwidth of filter 1 be B_1 and that of filter 2 be B_2 . The value of B_1/B_2 is



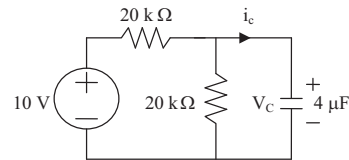
- (a) 4 (b) 1
(c) 1/2 (d) 1/4

66. For the circuit shown in the figure, the Thevenin voltage and resistance looking into $X-Y$ are



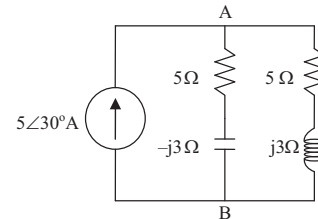
- (a) $\frac{4}{3}V, 2\Omega$ (b) $4V, \frac{2}{3}\Omega$
(c) $\frac{4}{3}V, \frac{2}{3}\Omega$ (d) $4V, 2\Omega$

67. In the circuit shown, V_C is 0 volts at $t = 0$ sec. For $t > 0$, the capacitor current $i_c(t)$, where t is in seconds, is given by



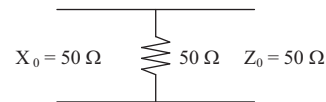
- (a) $0.50 e^{(-25t)}$ mA (b) $0.25 e^{(-25t)}$ mA
(c) $0.50 e^{(-12.5t)}$ mA (d) $0.25 e^{(-6.25t)}$ mA

68. In the AC network shown in the figure, the phasor voltage V_{AB} (in Volts) is



- (a) 0 (b) $5 \angle 30^\circ$
(c) $12.5 \angle 30^\circ$ (d) $17 \angle 30^\circ$

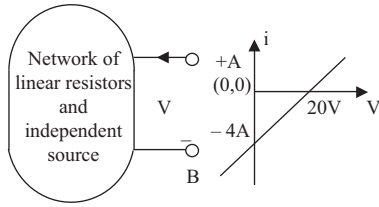
69. A load of 50Ω is connected in shunt in a 2-wire transmission line of $Z_0 = 50\Omega$ as shown in the figure. The 2-port scattering parameter matrix (S-matrix) of the shunt element is



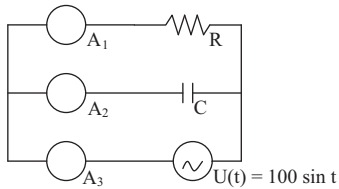
- (a) $\begin{bmatrix} -\frac{1}{2} & \frac{1}{2} \\ \frac{1}{2} & -\frac{1}{2} \end{bmatrix}$ (b) $\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$
(c) $\begin{bmatrix} -\frac{1}{3} & \frac{2}{3} \\ \frac{2}{3} & -\frac{1}{3} \end{bmatrix}$ (d) $\begin{bmatrix} \frac{1}{4} & -\frac{3}{4} \\ -\frac{3}{4} & \frac{1}{4} \end{bmatrix}$

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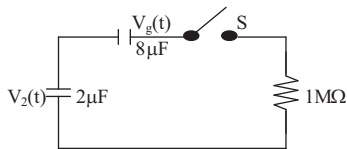
70. The V-I characteristic as seen from the terminal-pair (A, B) of the network of figure is shown in another figure. If a variable resistance R_L is connected across the terminal-pair (A, B), the maximum power that can be supplied to R_L would be



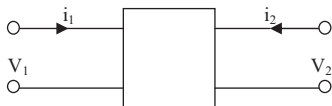
- (a) 80W
(b) 40W
(c) 20W
(d) indeterminate unless the actual network is given
71. In the figure shown, A_1 , A_2 and A_3 are ideal ammeters. If A_1 and A_3 read 5 and 13A respectively, reading of A_2 will be



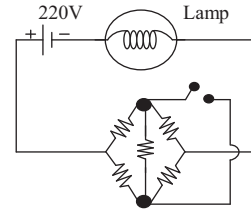
- (a) 8A
(b) 12A
(c) 18A
(d) Indeterminate unless the actual values of R, C and ω are specified
72. The switch S in figure is closed at $t = 0$. If $v_2(0) = 10V$ and $V_g(0) = 0V$ respectively, voltages across the capacitors in steady state will be



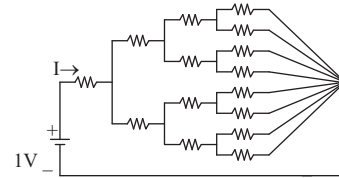
- (a) $v_2(\infty) = v_g(\infty) = 0$ (b) $v_g(\infty) = 2V$, $v_2(\infty) = 8$
(c) $v_2(\infty) = V_g(\infty) = 8V$ (d) $v_2(\infty) = v_g(\infty) = 2V$
73. The terminal voltage and currents of a two-port network are indicated in the figure. If the two-port is reciprocal, then



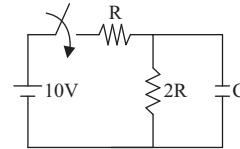
- (a) $[z_{12}/y_{12}] = z_{12}^2 - z_{11} \cdot z_{22}$ (b) $z_{12} = [1/y_{22}]$
(c) $h_{12} = -h_{21}$ (d) $AD - BC = 0$
74. All resistance in the circuit in figure are of R ohms. The switch is initially open. What happens to the lamp's intensity when the switch is closed?



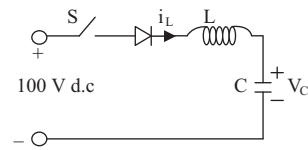
- (a) increases
(b) decreases
(c) remains the same
(d) answer depends on the value of R
75. All the resistances in figure are 1 each. The value of current 'I' is



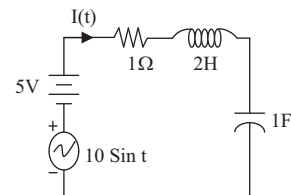
- (a) 1/15A (b) 2/15A
(c) 4/15A (d) 8/15A
76. The time constant of the network shown in the figure is



- (a) 2RC (b) 3RC
(c) RC/2 (d) 2RC/3
77. In the circuit of the figure below, the switch 'S' is closed at $t = 0$ with $i_L(0) = 0$ and $V_c(0) = 0$. In the steady state V_c equals

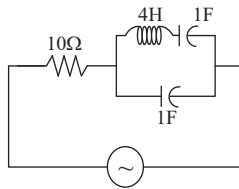


- (a) 200 V (b) 100 V
(c) zero (d) -100
78. In the following circuit figure $i(t)$ under steady state is



- (a) zero (b) 5
(c) $7.07 \sin t$ (d) $7.07 \sin(t - 45^\circ)$

79. The following circuit resonates at

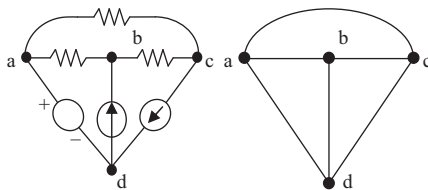


- (a) all frequencies (b) 0.5 rad/sec
(c) 5 rad/sec (d) 1 rad/sec

80. $s(t)$ is step response and $h(t)$ is impulse response of a system. Its response $y(t)$ for any input $u(t)$ is given by

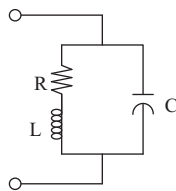
- (a) $\frac{d}{dt} \int_0^t s(t-\tau) u(\tau) d\tau$
(b) $\int_0^t s(t-\tau) u(\tau) d\tau$
(c) $\int_0^t \int_0^t s(t-\tau_1) u(\tau_1) d\tau_1 d\tau$
(d) $\frac{d}{dt} \int_0^t h(t-\tau) u(\tau) d\tau$

81. Figure below shows a dc resistive network and its graph is drawn aside. A 'proper tree' chosen for analysing the network will contain the edges



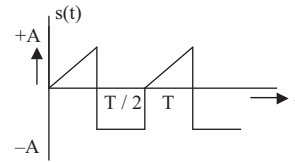
- (a) ab, bc, ad
(b) ab, bc, ca
(c) ab, bd, cd
(d) ac, bd, ad

82. At resonance, the parallel circuit of the figure below constituted by an iron-cored coil and a capacitor behaves like



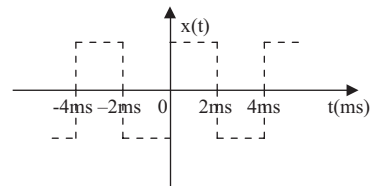
- (a) An open-circuit
(b) A short-circuit
(c) A pure resistor of value R
(d) A pure resistor of value much higher than R

83. The rms value of the periodic waveform $e(t)$, shown in the figure below is



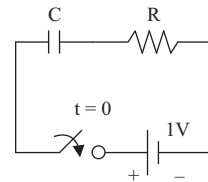
- (a) $\sqrt{3/2}$ A (b) $\sqrt{2/3}$ A
(c) $\sqrt{1/3}$ A (d) $\sqrt{2}$ A

84. A periodic rectangular signal, $x(t)$ has the wave form shown in the figure frequency of the fifth harmonic of its spectrum is



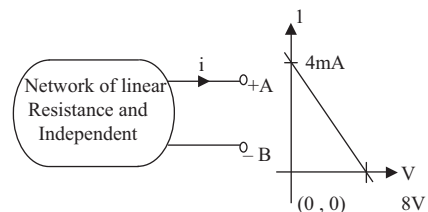
- (a) 40 Hz (b) 200 Hz
(c) 250 Hz (d) 1250 Hz

85. In the series RC circuit shown in the figure, the voltage across C starts increasing the dc source is switched on. The rate of increase of voltage across C at the instant just after the switch is closed (i.e., at $t = 0^+$), will be



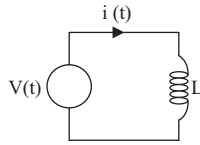
- (a) zero (b) infinity
(c) RC (d) $1/RC$

86. The v-i characteristic as seen from the terminal pair (A, B) of the network of the figure below is shown in another figure. If an inductance of value 6 mH is connected across the terminal-pair (A, B), the time constant of the system will be

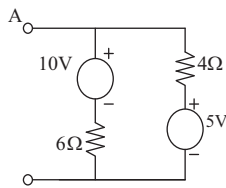


- (a) 3 μ sec
(b) 12 sec
(c) 32 sec
(d) unknown, unless the actual network is specified

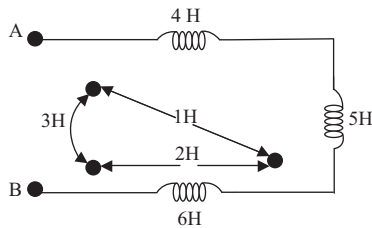
87. In the circuit shown in the figure below, it is desired to have a **constant direct current** $i(t)$ through the ideal inductor L . The nature of the voltage source $v(t)$ must be



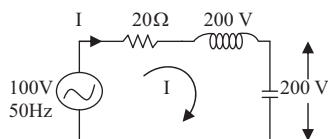
- (a) Constant voltage
(b) Linearly increasing voltage
(c) An ideal impulse
(d) Exponentially increasing voltage
88. Viewed from the terminals A, B the following circuit shown in the figure below can be reduced to an equivalent circuit of a single voltage source in series with a single resistance with the following parameters



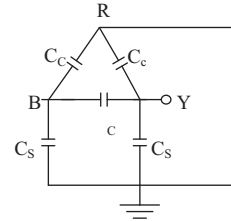
- (a) 5 volt source in series with $10\ \Omega$ resistor
(b) 1 volt source in series with $2.4\ \Omega$ resistance
(c) 7 volt source in series with $2.4\ \Omega$ resistance
(d) 1 volt in series in with $10\ \Omega$ resistor
89. The effective inductance of the circuit across the terminals A, B the figure shown below is



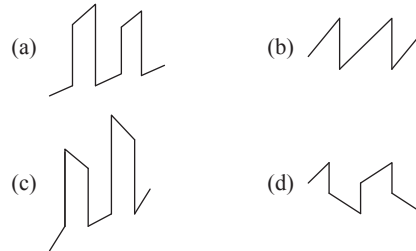
- (a) 9 H
(b) 21 H
(c) 11 H
(d) 6 H
90. Current in the circuit shown in the figure is



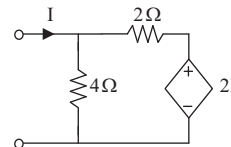
- (a) 5 A
(b) 10 A
(c) 15 A
(d) 25 A
91. For the circuit shown in the figure, the capacitance measured between terminals B and Y will be



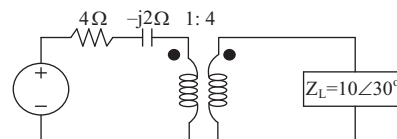
- (a) $C_c + (C_s/2)$
(b) $C_s + (C_c/2)$
(c) $[(C_s + 3C_c)/2]$
(d) $3C_c + 2C_c$
92. When a *periodic triangular* voltage of peak amplitude 1V and frequency 0.5 Hz is applied to a parallel combination of $1\ \Omega$ resistance and $1\ F$ capacitance, the current through the voltage source has wave-form



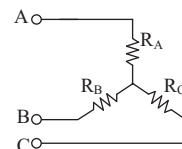
93. The circuit shown in the figure is equivalent to a load of



- (a) $[4/8]$ ohms
(b) $[8/3]$ ohm
(c) 4 ohm
(d) 2 ohms
94. The impedance seen by the source in the circuit in the figure is given by

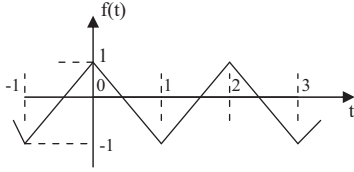


- (a) $0.54 + j0.313$ ohms
(b) $4 - j2$ ohms
(c) $4.54 - j1.69$ ohms
(d) $4 + j2$ ohms
95. Consider the star network shown in the figure. The resistance between terminals A and B with C open is $6\ \Omega$, between terminals B and C with A open is $11\ \Omega$, and between terminals C and A with B open is $9\ \Omega$. Then



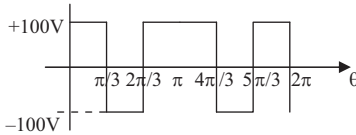
- (a) $R_A = 4 \Omega$, $R_B = 2 \Omega$, $R_C = 5 \Omega$
 (b) $R_A = 2 \Omega$, $R_B = 4 \Omega$, $R_C = 7 \Omega$
 (c) $R_A = 3 \Omega$, $R_B = 3 \Omega$, $R_C = 4 \Omega$
 (d) $R_A = 5 \Omega$, $R_B = 1 \Omega$, $R_C = 10 \Omega$

96. Fourier Series for the waveform, $f(t)$ shown in the figure is



- (a) $\frac{8}{\pi^2} \left\{ \sin(\pi t) + \frac{1}{9} \sin(3\pi t) + \frac{1}{25} \sin(5\pi t) + \dots \right\}$
 (b) $\frac{8}{\pi^2} \left\{ \sin(\pi t) - \frac{1}{9} \cos(3\pi t) + \frac{1}{25} \sin(5\pi t) + \dots \right\}$
 (c) $\frac{8}{\pi^2} \left\{ \cos(\pi t) + \frac{1}{9} \cos(3\pi t) + \frac{1}{25} \cos(5\pi t) + \dots \right\}$
 (d) $\frac{8}{\pi^2} \left\{ \cos(\pi t) - \frac{1}{9} \sin(3\pi t) + \frac{1}{25} \cos(5\pi t) + \dots \right\}$

97. What is the rms value of the voltage waveform shown in the figure?

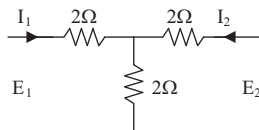


- (a) $200/\pi$ V (b) $100/\pi$ V
 (c) 200 V (d) 100 V

98. A two port network, shown in the figure is described by the following equations:

$$I_1 = y_{11} E_1 + y_{12} E_2$$

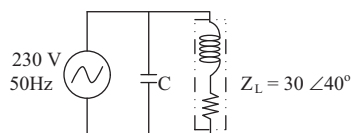
$$I_2 = y_{21} E_1 + y_{22} E_2$$



The admittance parameters, y_{11} , y_{12} , y_{21} and y_{22} for the network shown are

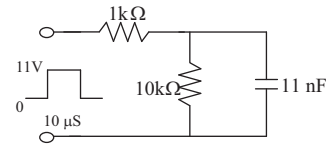
- (a) 0.5 mho, 1 mho, 2 mho and 1 mho respectively
 (b) $[1/3]$ mho, $-[1/6]$ mho, and $[1/3]$ mho respectively
 (c) 0.5 mho, 0.5 mho, 1.5 mho and 2 mho respectively
 (d) $-[2/5]$ mho, $-[3/7]$ mho and $[2/5]$ mho respectively

99. In the circuit shown in the figure, what value of C will cause a unity power factor at the ac source?



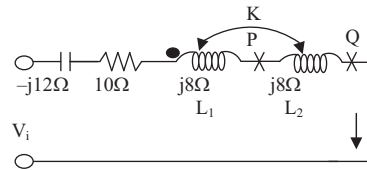
- (a) 68.1 μ F (b) 165 μ F
 (c) 0.681 μ F (d) 6.81 μ F

100. An 11 V pulse of 10 μ s duration is applied to the circuit shown in the figure. Assuming that the capacitor is completely discharged prior to applying the pulse, the peak value of the capacitor voltage is



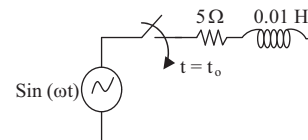
- (a) 11 V (b) 5.5 V
 (c) 6.31 V (d) 0.96 V

101. In the circuit shown in the figure, it is found that the input ac voltage (v_i) and current i are in phase. The coupling coefficient is $K = [M/\sqrt{L_1 L_2}]$, where M is mutual inductance between the two coils. The value of K and the dot polarity of the coil $P-Q$ are



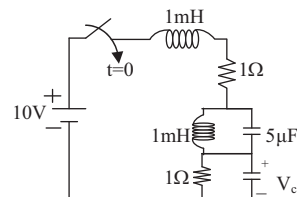
- (a) $K = 0.25$ and dot at P
 (b) $K = 0.25$ and dot at P
 (c) $K = 0.25$ and dot at Q
 (d) $K = 0.5$ and dot at Q

102. Consider the circuit shown in the figure. If the frequency of the source is 50 Hz, then a values of t_0 which results in a transient free response is



- (a) 0 ms (b) 1.78 ms
 (c) 2.71 ms (d) 2.91 ms

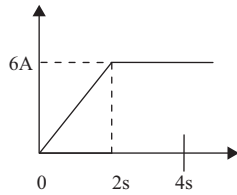
103. In the circuit shown in the figure, the switch is closed at time $t = 0$. The steady state value of the voltage v_c is



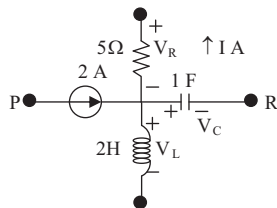
- (a) 0 V (b) 10 V
 (c) 5 V (d) 2.5 V

4.42 ■ Network Theory

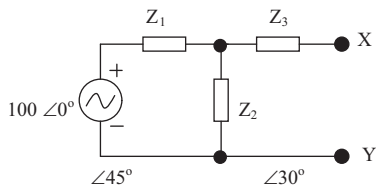
104. Figure shows the waveform of the circuit passing through an inductor of resistance $1\ \Omega$ and inductance $2\ \text{H}$. The energy absorbed by the inductor in the first four seconds is



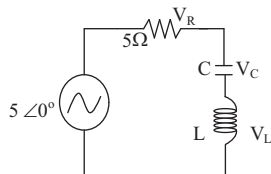
- (a) 144 J (b) 98 J
(c) 132 J (d) 168 J
105. A segment of a circuit is shown in the figure. $V_R = 5\text{V}$, $V_C = 4\sin 2t$. The voltage V_L is given by



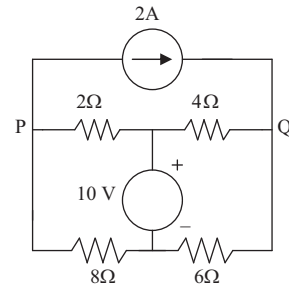
- (a) $3 - 8\cos 2t$ (b) $32\sin 2t$
(c) $16\sin 2t$ (d) $16\cos 2t$
106. In the figure, $Z_1 = 10\angle -60^\circ$, $Z_2 = 10\angle 60^\circ$, $Z_3 = 50\angle 53.13^\circ$. Thevenin impedance seen from $X - Y$ is



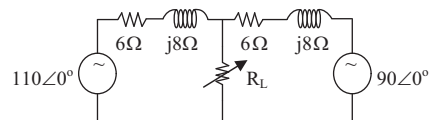
- (a) $56.67\angle 45^\circ$ (b) $60\angle 30^\circ$
(c) $70\angle 30^\circ$ (d) $34.4\angle 65^\circ$
107. In the circuit of the figure, the magnitudes of V_L and V_C are twice that of V_R . The inductance of the coil is



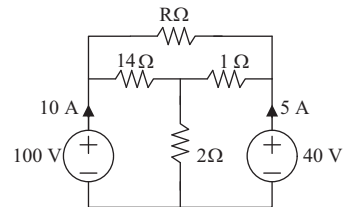
- (a) 2.14 mH (b) 5.30 H
(c) 3.18 mH (d) 1.32 H
108. In figure, the potential difference between points P and Q is



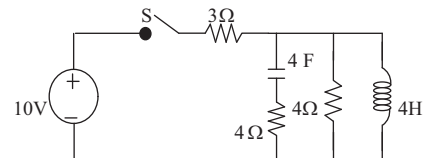
- (a) 12 V (b) 10 V
(c) -6 V (d) 8 V
109. Two a.c. source feed a common variable resistive load as shown in the figure. Under the maximum power transfer condition, the power absorbed by the load resistance R_L is



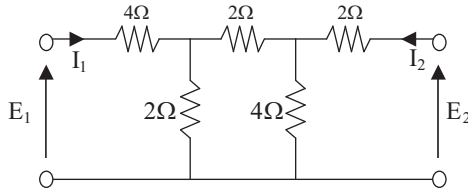
- (a) 2200 W (b) 1250 W
(c) 1000 W (d) 625 W
110. In the figure, the value of R is



- (a) 10 Ω (b) 18 Ω
(c) 24 Ω (d) 12 Ω
111. In the circuit shown in the figure, the switch S is closed at time $t = 0$. The voltage across the inductance at $t = 0^+$ is

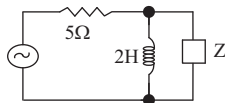


- (a) 2 V (b) 4 V
(c) -6 V (d) 8 V
112. The h parameters for a two-port network are defined by
- $$\begin{bmatrix} E_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ E_2 \end{bmatrix}$$
- For the two-port network shown in the figure, the value of h_{12} is given by



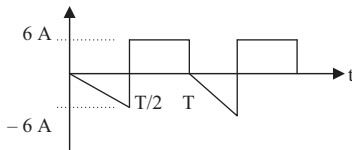
- (a) 0.125 (b) 0.167
(c) 0.625 (d) 0.25

113. The value of Z in the figure which is most appropriate to cause parallel resonance at 500 Hz is



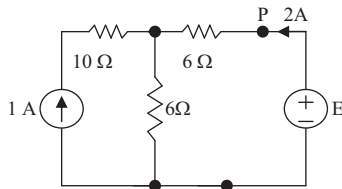
- (a) 125.00 mH (b) 304.20 μ F
(c) 2.0 μ F (d) 0.05 μ F

114. The rms value of the periodic waveform given in the figure is



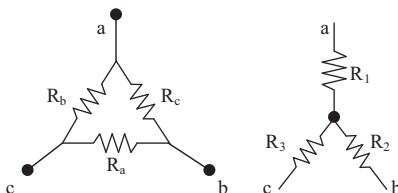
- (a) $2\sqrt{6}$ A (b) $6\sqrt{2}$ A
(c) $\sqrt{\frac{4}{3}}$ A (d) 1.5 A

115. In the figure, the value of the source voltage is



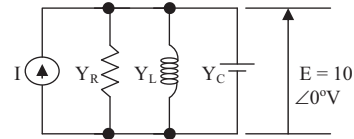
- (a) 12 V (b) 24 V
(c) 30 V (d) 44 V

116. In the figure, R_a , R_b and R_c are 20 Ω , 10 Ω , 10 Ω respectively. The resistance R_1 , R_2 and R_3 in Ω of an equivalent star-connection are



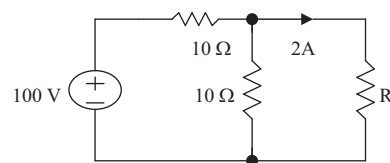
- (a) 2.5, 5, 5 (b) 5, 2.5, 5
(c) 5, 5, 2.5 (d) 2.5, 5, 2.5

117. In the figure, the admittance values of the elements in Siemens are $Y_R = 0.5 + j0$, $Y_L = 0 - j1.5$, $Y_C = 0 + j0.3$ respectively. The value of I as a phasor when the voltage E across the elements is $10\angle 0^\circ$ is



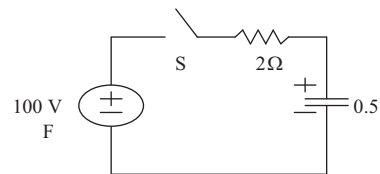
- (a) $1.5 + j0.5$ (b) $5 - j18$
(c) $0.5 + j1.8$ (d) $5 - j2$

118. In the figure, the value of resistance R in Ω is



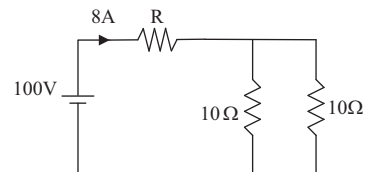
- (a) 10 (b) 20
(c) 30 (d) 40

119. In the figure, the capacitor initially has a charge of 10 Coulomb. The current in the circuit one second after the switch S is closed will be



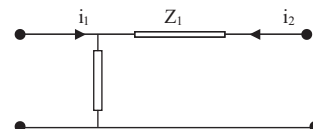
- (a) 14.7 A (b) 18.5 A
(c) 40.0 A (d) 50.0 A

120. In the figure given below, the value of R is



- (a) 2.5 Ω (b) 5.0 Ω
(c) 7.5 Ω (d) 10.0 Ω

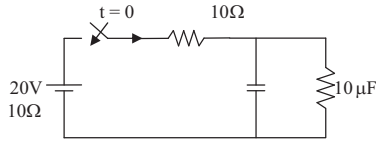
121. For the two port network shown in the figure, the Z -matrix is given by



4.44 ■ Network Theory

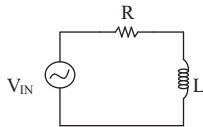
- (a) $\begin{bmatrix} Z_1 & Z_1 + Z_2 \\ Z_1 + Z_2 & Z_2 \end{bmatrix}$ (b) $\begin{bmatrix} Z_1 & Z_1 \\ Z_1 + Z_2 & Z_2 \end{bmatrix}$
 (c) $\begin{bmatrix} Z_1 & Z_2 \\ Z_2 & Z_1 + Z_2 \end{bmatrix}$ (d) $\begin{bmatrix} Z_1 & Z_1 \\ Z_1 & Z_1 + Z_2 \end{bmatrix}$

122. In the figure given below, the initial capacitor voltage is zero. The switch is closed at $t = 0$. The final steady-state voltage across the capacitor is



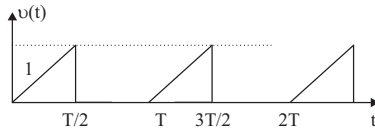
- (a) 20 V (b) 10 V
 (c) 5 V (d) 0 V

123. The RL circuit of the figure is fed from a constant magnitude, variable frequency sinusoidal voltage source V_{IN} . At 100 Hz. The R and L elements each have a voltage drop V_{RMS} . If the frequency of the source is changed to 50 Hz, then new voltage drop across R is



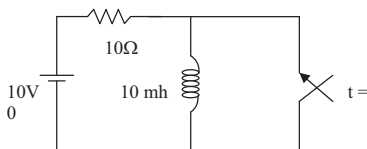
- (a) $\sqrt{\frac{5}{8}} u_{RMS}$ (b) $\sqrt{\frac{2}{3}} u_{RMS}$
 (c) $\sqrt{\frac{8}{5}} u_{RMS}$ (d) $\sqrt{\frac{3}{2}} u_{RMS}$

124. For the triangular waveform shown in the figure, the RMS value of the voltage is equal to



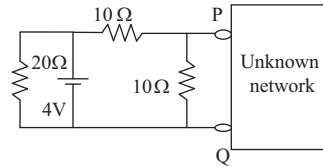
- (a) $\sqrt{\frac{1}{6}}$ (b) $\sqrt{\frac{1}{3}}$
 (c) $\frac{1}{3}$ (d) $\sqrt{\frac{2}{3}}$

125. The circuit shown in the figure is in steady state, when the switch is closed at $t = 0$. Assuming that the inductance is ideal, the current through the inductor at $t = 0^+$ equals



- (a) 0 A (b) 0.5 A
 (c) 1 A (d) 5 A

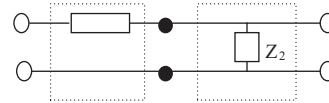
126. In the figure, the Thevenin's equivalent pair (voltage, impedance), as seen at the terminals $P-Q$, is given by



- (a) (2V, 5Ω) (b) (2V, 7.5Ω)
 (c) (4V, 5Ω) (d) (4V, 7.5Ω)

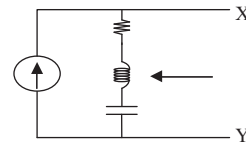
127. Two networks are connected in the cascade as shown in the figure. With the equal notations the equivalent A , B , C and D constants are obtained. Given that, $C = 0.025 \angle 45^\circ$, the value of Z_2 is

$$Z_1 = 10 \angle 30^\circ \Omega$$



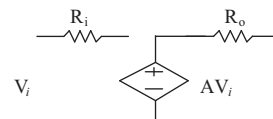
- (a) $10 \angle 30^\circ \Omega$ (b) $40 \angle -45^\circ$
 (c) 1 Ω (d) 0 Ω

128. In the figure, the current source is $1 \angle 0^\circ A$, $R = 1 \Omega$, the impedances are $Z_C = -j\Omega$, and $Z_1 = 2j\Omega$. The thevenin equivalent looking into the circuit across $X-Y$ is



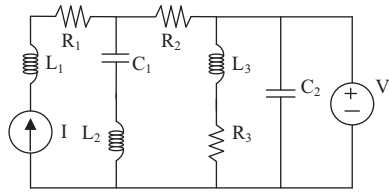
- (a) $\sqrt{2} \angle 0^\circ V, (1 + 2j) \Omega$
 (b) $2 \angle 45^\circ V, (1 - 2j) \Omega$
 (c) $2 \angle 45^\circ V, (1 + j) \Omega$
 (d) $\sqrt{2} \angle 45^\circ V, (1 + j) \Omega$

129. The parameters of the circuit shown in the figure are $R_1 = 1 M \Omega$, $R_0 = 10 \Omega$, $A = 10^6 V/V$. If $V_i = 1 \mu V$ the output voltage, input impedance and output impedance respectively are



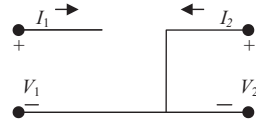
- (a) 1 V, ∞ , 10 Ω (b) 1 V, 0, 10 Ω
 (c) 1 V, 0, ∞ (d) 10 V, ∞ , 10 Ω

130. In the circuit shown in the figure, the current source $I = 1 A$, the voltage source $V = 5V$, $R_1 = R_2 = R_3 = 1 \Omega$, $L_1 = L_2 = L_3 = 1H$, $C_1 = C_2 = 1F$. The currents (in A) through R_3 and the voltage source V respectively will be



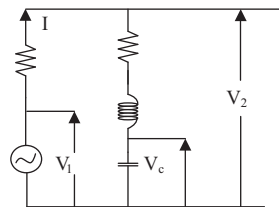
- (a) 1, 4
(b) 5, 1
(c) 5, 2
(d) 5, 4

131. The parameter type and the matrix representation of the relevant two port parameter that describe the circuit shown are

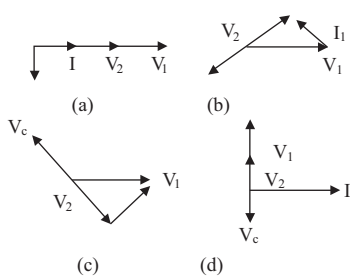


- (a) z parameters, $\begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$ (b) h parameters, $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$
(c) h parameters, $\begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$ (d) z parameters, $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

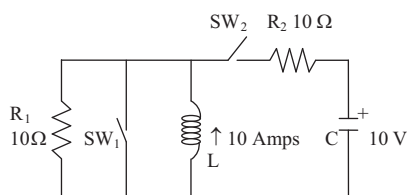
132. The circuit shown in the figure is energized by a sinusoidal voltage source V_1 at a frequency which causes resonance with a current of I



The phasor diagram which is applicable to this circuit is

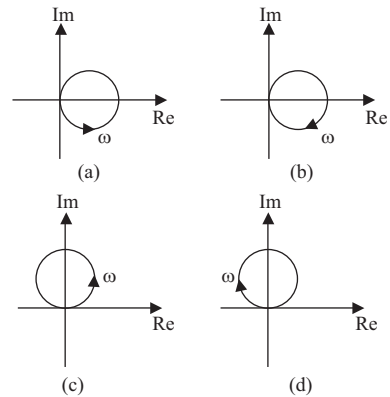
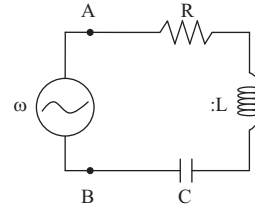


133. In the circuit shown in the figure, switch SW_1 is initially CLOSED and SW_2 is OPEN. The inductor L carries a current 10 A and the capacitor is charged to 10 V with polarities as indicated. SW_2 is initially CLOSED at $t = 0^-$ and SW_1 is OPENED at $t = 0$. The current through C and the voltage across L at $t = 0^+$ is

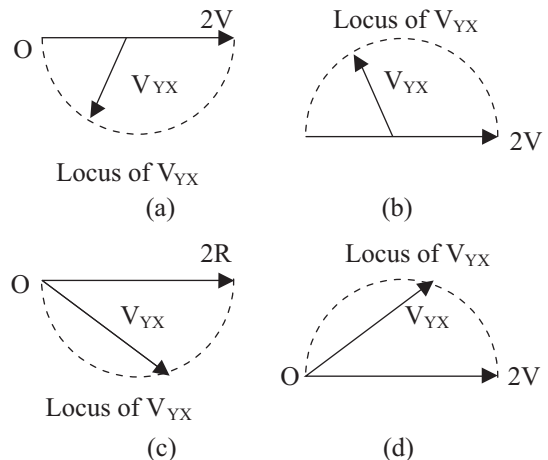
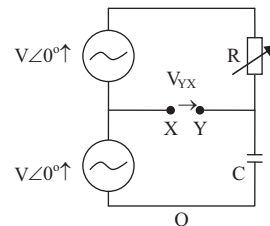


- (a) 55 A, 4.5 V (b) 5.5 A, 45 V
(c) 45 A, 5.5 V (d) 4.5 A, 55 V

134. The R-L-C series circuit shown in the figure is supplied from a variable frequency voltage source. The admittance-locus of the R-L-C network at terminals AB for increasing frequency ω is



135. In the figure given below, all phasors are with reference to the potential at point "O". The locus of voltage phasor V_{YX} as R is varied from zero to infinity is shown by



ANSWER KEYS

LEVEL 1

1. (c)	2. (c)	3. (c)	4. (d)	5. (b)	6. (b)	7. (d)	8. (c)	9. (b)	10. (a)
11. (b)	12. (d)	13. (b)	14. (d)	15. (c)	16. (a)	17. (d)	18. (d)	19. (d)	20. (b)
21. (b)	22. (b)	23. (b)	24. (b)	25. (a)	26. (b)	27. (c)	28. (c)	29. (c)	30. (c)
31. (c)	32. (c)	33. (b)	34. (c)	35. (d)	36. (c)	37. (b)	38. (d)	39. (c)	40. (b)
41. (b)	42. (c)	43. (d)	44. (c)	45. (d)	46. (c)	47. (d)	48. (d)	49. (a)	50. (a)
51. (b)	52. (d)	53. (d)	54. (b)	55. (c)	56. (c)	57. (a)	58. (d)	59. (a)	60. (c)
61. (d)	62. (c)	63. (b)	64. (c)	65. (b)	66. (c)	67. (b)	68. (a)	69. (b)	70. (b)
71. (c)	72. (d)	73. (a)	74. (b)	75. (a)	76. (a)	77. (d)	78. (a)	79. (d)	80. (c)
81. (c)	82. (b)	83. (a)	84. (d)	85. (b)	86. (a)	87. (c)	88. (b)	89. (d)	90. (c)
91. (b)	92. (c)	93. (c)	94. (d)	95. (b)	96. (d)	97. (c)	98. (c)	99. (a)	100. (b)

LEVEL 2

1. (c)	2. (d)	3. (c)	4. (c)	5. (c)	6. (c)	7. (d)	8. (c)	9. (b)	10. (d)
11. (c)	12. (c)	13. (c)	14. (c)	15. (c)	16. (b)	17. (c)	18. (b)	19. (c)	20. (b)
21. (c)	22. (b)	23. (c)	24. (b)	25. (d)	26. (d)	27. (c)	28. (a)	29. (c)	30. (d)
31. (c)	32. (c)	33. (b)	34. (a)	35. (b)	36. (a)	37. (d)	38. (b)	39. (c)	40. (a)
41. (d)	42. (a)	43. (b)	44. (a)	45. (b)	46. (d)	47. (b)	48. (b)	49. (c)	50. (c)
51. (a)	52. (d)	53. (b)	54. (a)	55. (a)	56. (b)	57. (c)	58. (b)	59. (d)	60. (c)
61. (c)	62. (d)	63. (d)	64. (a)	65. (c)	66. (b)	67. (c)	68. (b)	69. (c)	70. (c)
71. (c)	72. (b)	73. (a)	74. (a)	75. (c)	76. (c)	77. (c)	78. (c)	79. (c)	80. (c)
81. (c)	82. (d)	83. (a)	84. (a)	85. (d)	86. (b)	87. (d)	88. (c)	89. (d)	90. (c)
91. (b)	92. (c)	93. (c)	94. (b)	95. (a)	96. (b)	97. (c)	98. (b)	99. (b)	100. (c)

LEVEL 3

1. (c)	2. (b)	3. (c)	4. (d)	5. (a)	6. (b)	7. (d)	8. (a)	9. (a)	10. (c)
11. (d)	12. (d)	13. (a)	14. (a)	15. (c)	16. (c)	17. (a)	18. (c)	19. (a)	20. (b)
21. (c)	22. (d)	23. (b)	24. (a)	25. (d)	26. (d)	27. (b)	28. (a)	29. (c)	30. (a)
31. (a)	32. (d)	33. (a)	34. (d)	35. (b)	36. (d)	37. (b)	38. (c)	39. (c)	40. (a)
41. (d)	42. (d)	43. (d)	44. (b)	45. (d)	46. (d)	47. (b)	48. (d)	49. (a)	50. (a)
51. (c)	52. (b)	53. (c)	54. (a)	55. (b)	56. (b)	57. (c)	58. (d)	59. (b)	60. (a)
61. (b)	62. (a)	63. (b)	64. (b)	65. (d)	66. (d)	67. (a)	68. (d)	69. (b)	70. (c)
71. (b)	72. (b)	73. (c)	74. (c)	75. (d)	76. (d)	77. (b)	78. (d)	79. (b)	80. (a)
81. (a)	82. (d)	83. (b)	84. (d)	85. (d)	86. (a)	87. (c)	88. (c)	89. (c)	90. (a)
91. (c)	92. (d)	93. (b)	94. (c)	95. (b)	96. (c)	97. (d)	98. (b)	99. (a)	100. (d)
101. (c)	102. (b)	103. (c)	104. (a)	105. (b)	106. (a)	107. (c)	108. (c)	109. (d)	110. (d)
111. (d)	112. (a)	113. (d)	114. (a)	115. (c)	116. (a)	117. (a)	118. (b)	119. (a)	120. (c)
121. (d)	122. (d)	123. (c)	124. (a)	125. (c)	126. (a)	127. (b)	128. (d)	129. (a)	130. (d)
131. (c)	132. (a)	133. (d)	134. (a)	135. (c)					

ELECTROMAGNETIC THEORY

5.1 VECTOR OPERATION, COORDINATE SYSTEM AND VARIOUS DELTA OPERATIONS

Scalar

A quantity that is characterized only by magnitude and algebraic sign is called a scalar. For example, mass, time, temperature and work.

Vector

A quantity that has direction as well as magnitude is called vector. For example, are force, velocity, displacement and acceleration.

A vector can be represented geometrically by an arrow whose direction is appropriate by chosen and whose length is proportional to the magnitude of the vector.

Field

If at each point of a region, there is a corresponding value of some physical function, the region is called a field. Fields may be classified as either scalar or vector, depending upon the type of function involved.

Multiplication of a scalar and a vector

$$\vec{C} = Aa\vec{B}$$

Scalar Multiplication/Dot product

$$\vec{A} \cdot \vec{B} = A B \cos \theta$$

Vector Multiplication/Cross Product

$$\vec{A} \times \vec{B} = A B \sin \theta \hat{a}_n$$

$\hat{a}_n$ -Unit normal vector perpendicular to the plane made by a $\vec{A}$ and $\vec{B}$.

Differential Integrals

- (a) Line integral

$$\int_c \vec{A} \cdot d\vec{\ell}$$

- (b) Close line integral

$$\oint_c \vec{A} \cdot d\vec{\ell}$$

any closed curve C always encloses some surface area S .

- (c) Surface integral

$$\iint_s \vec{A} \cdot d\vec{s}$$

- (d) Closed surface integral

$$\oiint_s \vec{A} \cdot d\vec{s}$$

Any closed surface area always encloses some volume area.

- (e) Volume integral

$$\int_v \vec{A} \, dv$$

Theorems

- (a) Stroke's theorem

$$\oint_c \vec{A} \cdot d\vec{\ell} = \iiint (\nabla \times \vec{A}) \, ds \text{ Del Operator/3D Differential}$$

Vector Operator

$$\nabla = \hat{a}_x \frac{\partial}{\partial x} + \hat{a}_y \frac{\partial}{\partial y} + \hat{a}_z \frac{\partial}{\partial z}$$

Mathematical Relationships for Different Operators

$$\begin{aligned}
 1. \quad \nabla V &= \frac{1}{h_1} \frac{\partial V}{\partial u} \hat{a}_u + \frac{1}{h_2} \frac{\partial V}{\partial v} \hat{a}_v + \frac{1}{h_3} \frac{\partial V}{\partial w} \hat{a}_w \\
 2. \quad \nabla \cdot \vec{A} &= \frac{1}{h_1 h_2 h_3} \left(\frac{\partial}{\partial u} (h_2 h_3 A_u) + \frac{\partial}{\partial v} (h_3 h_1 A_v) + \frac{\partial}{\partial w} (h_1 h_2 A_w) \right) \\
 3. \quad \nabla \times \vec{A} &= \frac{1}{h_1 h_2 h_3} \begin{vmatrix} h_1 \hat{a}_u & h_2 \hat{a}_v & h_3 \hat{a}_w \\ \frac{\partial}{\partial u} & \frac{\partial}{\partial v} & \frac{\partial}{\partial w} \\ h_1 A_u & h_2 A_v & h_3 A_w \end{vmatrix} \\
 4. \quad \nabla^2 V &= \frac{1}{h_1 h_2 h_3} \left(\frac{\partial}{\partial u} \left(\frac{h_2 h_3}{h_1} \frac{\partial V}{\partial u} \right) + \frac{\partial}{\partial v} \left(\frac{h_3 h_1}{h_2} \frac{\partial V}{\partial v} \right) + \frac{\partial}{\partial w} \left(\frac{h_1 h_2}{h_3} \frac{\partial V}{\partial w} \right) \right)
 \end{aligned}$$

where, $\vec{A} = A_u \hat{a}_u + A_v \hat{a}_v + A_w \hat{a}_w$.

Physical Interpretation of Different Operator Gradient of Scalar ($\nabla \cdot \mathbf{v}$)

$$\text{Grad } v = \nabla v = \frac{\partial v}{\partial x} \hat{a}_x + \frac{\partial v}{\partial y} \hat{a}_y + \frac{\partial v}{\partial z} \hat{a}_z$$

Formulas:

- $\nabla (U + V) = \nabla U + \nabla V$
- $\nabla (U \cdot V) = V \nabla U + U \nabla V$
- $\nabla \left(\frac{V}{U} \right) = \frac{U \nabla V - V \nabla U}{U^2}$
- $\nabla V^n = n V^{n-1} \nabla V$

Divergence of a Vector

The divergence of A at point P is the outward flux per unit volume as the volume shrinks about P .

$$\text{div } \vec{A} = \nabla \cdot \vec{A} = \lim_{\Delta v \rightarrow 0} \frac{\oint \vec{A} \cdot d\vec{s}}{\Delta v}$$

Divergence and Curl

- The divergence of a continuously differentiable function vector $\vec{F}$ is denoted by $\nabla \cdot \vec{F}$ and is defined by equation

$$\text{Div. } \vec{F} = \nabla \cdot \vec{F} = \frac{\partial \vec{F}}{\partial x} \hat{i} + \frac{\partial \vec{F}}{\partial y} \hat{j} + \frac{\partial \vec{F}}{\partial z} \hat{k}$$

Physical interpretation: Divergence V , where V is any physical quantity, gives at each point the rate per unit volume at which the quantity is issuing from that point.

Solenoidal Function: For a vector point function, $\vec{V}$, if $\text{div } \vec{V} = 0$, $\vec{V}$ is a solenoidal function

$$\nabla V = \frac{\partial V}{\partial x} \hat{i} + \frac{\partial V}{\partial y} \hat{j} + \frac{\partial V}{\partial z} \hat{k}$$

- The curl of a continuously differentiable vector point function $\vec{F}$ is denoted by $\text{curl } \vec{F}$.

$$\text{Curl } \vec{F} = \nabla \times \vec{F} = \hat{i} \times \frac{\partial \vec{F}}{\partial x} + \hat{j} \times \frac{\partial \vec{F}}{\partial y} + \hat{k} \times \frac{\partial \vec{F}}{\partial z}$$

$$\text{If } \vec{F} = f \hat{i} + \phi \hat{j} + \psi \hat{k}$$

$$\text{Then } \nabla \times \vec{F} = \left(\frac{\partial}{\partial x} \hat{i} + \frac{\partial}{\partial y} \hat{j} + \frac{\partial}{\partial z} \hat{k} \right) \times (f \hat{i} + \phi \hat{j} + \psi \hat{k})$$

Curl of any vector point function, gives the angular velocity at the point

Irrotational Function: If for a vector point function $\vec{V}$, $\text{curl } \vec{V} = 0$, $\vec{V}$ is irrotational.

Curl of a Vector

The curl of A is an axial (or rotational) vector whose magnitude is the maximum circulation of A per unit area as the area tends to zero and whose direction is the normal direction of area when the area is oriented so on to make the circulation maximum.

$$\text{Curl } \vec{A} = \nabla \times \vec{A} = \lim_{\Delta s \rightarrow 0} \left(\frac{\oint \vec{A} \cdot d\vec{l}}{\Delta s} \right) \hat{a}_n$$

In Electrical Sense

$$\nabla \times \vec{E} = 0 \rightarrow \text{Static electric field is irrotational}$$

$$\nabla \times \vec{E} = \frac{\partial \vec{B}}{\partial t} \rightarrow \text{Time varying electric field has a non-zero curl}$$

$$\nabla \times \vec{H} = \vec{J} \rightarrow \text{Static magnetic field has a non-zero curl}$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \rightarrow \text{time varying magnetic field has also a non zero curl.}$$

Laplacian of a Scalar

It is a single operator which is the composite of gradient and divergence operator.

The Laplacian of a scalar field V written as $\nabla^2 V$ is the divergence of the gradient of V .

Laplacian $V = \nabla \cdot \nabla V = \nabla^2 V$

$$= \left(\frac{\partial}{\partial x} \hat{a}_x + \frac{\partial}{\partial y} \hat{a}_y + \frac{\partial}{\partial z} \hat{a}_z \right) \left(\frac{\partial v}{\partial x} \hat{a}_x + \frac{\partial v}{\partial y} \hat{a}_y + \frac{\partial v}{\partial z} \hat{a}_z \right) V$$

$\nabla^2 V = \nabla(\nabla V) = \text{Scalar quantity}$

This is represented as divergence of gradient of scalar quantity V .

Laplacian Operator has no Physical Interpretation

Laplacian of a scalar simply represents a second order differential form to find out the electrostatic problem.

Vector field

- (a) A vector field is $\vec{A}$ said to be solenoid (or divergences) if $\nabla \cdot \vec{A} = 0$

From divergence theorem

$$\oint_C \vec{A} \cdot \delta \vec{s} = \int_V \nabla \cdot \vec{A} \delta v = 0$$

Then $\nabla \cdot \vec{A} = 0$

$$\oint_s \vec{A} \cdot \delta \vec{s} = 0 \text{ and } F = \nabla \times \vec{A}$$

- (b) A vector field is $\vec{A}$ said to be irrotational (or potential) if $\nabla \times \vec{A} = 0$.

From stroke theorem,

$$\int_V (\nabla \times \vec{A}) \cdot \delta \vec{s} = \oint_s \vec{A} \cdot \delta \vec{l} = 0$$

Then $\nabla \times \vec{A} = 0$

$$\vec{A} \cdot \delta \vec{l} = 0 \text{ and } A = \nabla V$$

- (b) $\nabla \cdot \vec{A} = \rho_v$ volume charge density

$\nabla \times \vec{A} = \rho_s$ surface charge density

$$\vec{A} = -\nabla V + \nabla \times \vec{B}$$

$$\nabla^2 A = \nabla \rho_v - \nabla \times \rho_s.$$

5.2 ELECTROSTATICS

Coulomb's Law

Force of attraction or repulsion between two charged particles is given by

$$F = \frac{q_1 q_2 \hat{a}_r}{4\pi \epsilon_0 |r|^2} = \frac{q_1 q_2}{4\pi \epsilon_0 |r|^2} \hat{a}_r$$

where, q_1, q_2 is value of charge in coulombs. r in meters

$\hat{a}_r = [\hat{r} / |r|] = \text{unit vector pointing in direction of line joining the two charge.}$

$$\bullet \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$$

Electric Field

Electric field strength E around a charge q is defined as force per unit charge and the magnitude is E .

$$E = \frac{q}{4\pi \epsilon_0 r^2} \hat{a}_r.$$

Electric Field at Distance

- (a) Due to line charge density ρ_l

$$E = \frac{1}{4\pi \epsilon_0} \int_{\text{line}} \frac{\rho_l}{r^2} dl \hat{a}_r$$

- (b) Due to surface charge density ρ_s

$$E = \frac{1}{4\pi \epsilon_0} \iint_{\text{surface}} \frac{\rho_s}{r^2} ds \hat{a}_r; \rho_s - \text{charge/unit area}$$

- (c) Due to volume charge density, ρ_v

$$E = \frac{1}{4\pi \epsilon_0} \iiint_{\text{Vol}} \frac{\rho_v}{r^2} dv \hat{a}_r.$$

Electric Potential

The work done in moving a charge, against the force F of charged q , from infinity to a point X at a distance R , is given as

$$\bullet \text{ Work done} = - \int_{\infty}^R F dr$$

$$\bullet \text{ Work done on test charge} = - \int_{-\infty}^R \frac{q \Delta q}{4\pi\epsilon_0 R^2} dr$$

$$W = \frac{q \Delta q}{4\pi\epsilon_0 R}$$

- $\bullet$ Work done per unit charge is known a potential

$$V = \frac{W}{\Delta q} = \frac{q}{4\pi\epsilon_0 R}$$

- $\bullet$ Electric field strength at any point is the negative of the potential gradient at the point.

$$E = -\nabla V.$$

Electric Potential at Distance

- (a) Due to line charge density ρ_l

$$V = \frac{1}{4\pi \epsilon_0} \int_{\text{line}} \frac{\rho_l}{r} dl \hat{a}_r$$

- (b) Due to surface charge density ρ_s

$$V = \frac{1}{4\pi \epsilon_0} \iint_{\text{surface}} \frac{\rho_s}{r} ds \hat{a}_r; \rho_s - \text{charge/unit area}$$

- (c) Due to volume charge density, ρ_v

$$V = \frac{1}{4\pi \epsilon_0} \iiint_{\text{Vol}} \frac{\rho_v}{r} dv \hat{a}_r$$

5.4 ■ Electromagnetic Theory

- **Torque** $\tau = PE \sin \theta = \vec{P} \times \vec{E}$
Where, θ is the angle, the line joining the charge makes with the electric field.
- **Charge density** $D = \frac{q}{4\pi r^2}$
- $D = \epsilon_0 E$, maximum value of 'D' is along the normal to the surface.

Gauss's Law

It states that the total displacement or electric flux enclosed by a surface surrounding charges is equal to the amount of charge enclosed.

$$\oint_s D \cdot ds = Q = \iiint_v \nabla \cdot D \, dv$$

- Gauss's law in differential form or Maxwell's 1 equation.

$$\nabla \cdot E = \frac{\rho}{\epsilon_0} \text{ or } \nabla \cdot D = \rho$$

Gauss's Law Used for Calculating Electric Fields

Gauss's law states that the electric flux passing through any closed surface is equal to the total charge enclosed by the surface.

If $\vec{D}$ denotes the electric flux density then we have

$$\int_s \vec{D} \cdot d\vec{s} = Q$$

where, Q is the total charge enclosed by s .

Thus if ρ be the charge density then $Q = \int_v \rho \, dv$

$$\int_s \vec{D} \cdot d\vec{s} = \int_v \rho \, dv$$

If E be the electric field then $\epsilon \vec{E} = \vec{D}$ where ϵ is the permittivity of the medium.

$$2 \int E \cdot ds = \int \frac{\rho \cdot ds}{\epsilon}$$

$$\therefore E = \frac{\rho}{2\epsilon}$$

Electric Field Due to Charged Conductor

An electric field due to a charged conductor can be through as that due to two charged sheets (a conductor is actually enclosed by two charged sheets such that electric field is zero at all interior points):

$$\therefore \text{Electric field is } \frac{\sigma}{2\epsilon} \times 2 = \frac{\sigma}{\epsilon}$$

Electrical Field Due to Line Charge

If we have a line charge with linear density ρ_L , the electric field at distance r is:

$$E = \frac{\rho}{2\pi \epsilon_0 r}$$

Spherical Charge Distributions

- Electrical field at external point due to uniformly charged thin spherical shell is same as due to an equal point charge

$$\text{placed at center and is } E = \frac{Q}{4\pi \epsilon r^2}.$$

The electric field, at an internal point, due to the thin spherical shell is zero.

- Electrical field due to a uniformly charged sphere at an external point is the same due to an equal charge placed at

$$\text{the center and is } E = \frac{Q}{4\pi \epsilon r^2}.$$

- Electric field, at an internal point, due to a uniformly charged sphere is proportional to the distance of the point

$$\text{from the centre and is given by } E = \frac{Qr}{4\pi \epsilon R^3} \text{ where } R \text{ is the radius.}$$

Electrical Potential Energy

If we have two charge systems Q_1 and Q_2 , the force between

$$\text{them is given by coulomb's law } \vec{F} = \frac{Q_1 Q_2}{4\pi \epsilon r^2} \vec{a}_r$$

Now let us consider keeping one charge fixed and moving the other along the direction of force. So work done by the force is

$$dw = \vec{F} \cdot d\vec{R} = \frac{Q_1 Q_2}{4\pi \epsilon r^2} \vec{a}_r \cdot d\vec{R}$$

The total work done as the charge moves from r_1 to r_2 is

$$\int_{r_1}^{r_2} \frac{Q_1 Q_2}{4\pi \epsilon r^2} dz = \frac{Q_1 Q_2}{4\pi \epsilon} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

The change in potential energy of the system $V(r_2) - V(r_1)$ is

$$-w = \frac{Q_1 Q_2}{4\pi \epsilon} \left(\frac{1}{r_2} - \frac{1}{r_1} \right)$$

Thus if work is done by the force, there is a decrease in potential energy and vice versa.

We choose the potential energy of two charge systems to be zero when they have infinite separation.

The potential when they are separated by a distance r is:

$$V(r) - V(\infty) = \frac{q_1 q_2}{4\pi \epsilon} \left(\frac{1}{r} - \frac{1}{\infty} \right) = \frac{q_1 q_2}{4\pi \epsilon r}$$

The above equation is derived by assuming that one of the charges remains fixed while the other is moved.

The electric potential difference between two points is defined as the difference in potential energy per unit charge.

$$\text{i.e., } V(r_1) - V(r_2) = \frac{V_{r1} - V_{r2}}{q}$$

Poisson's Equation and Laplace's Equation

- Poisson's equation $\nabla^2 V = -[\rho/\epsilon_0]$.
- In the region where there is no charge i.e., free space $\rho = 0$; $\nabla^2 V = 0$ known as *Laplace's equation*.
- Potential difference between points A and B is equal to the work done by unit charge to carry the particle from A to B.
- $W = \frac{\epsilon_0}{2} \int_{\text{all surface}} E^2 dv$.

Capacitances

- $C = \frac{q}{V} = \frac{\epsilon A}{d}$ [for parallel plate capacitor]
- Cylindrical capacitor

$$C = \frac{2\pi\epsilon}{\ln(b/a)}$$

where, a and b are radii of inner and outer conductors.

Energy Stored in a Capacitor

$$W_e = \frac{q^2}{2C} = \frac{CV^2}{2} = \frac{VQ}{2}$$

Dipole

A dipole is a part of charges of equal magnitude but opposite sign, separated by a small distance.

Dipole moment $P = dQ$

where, d = distance between charges,

Potential due to a dipole:

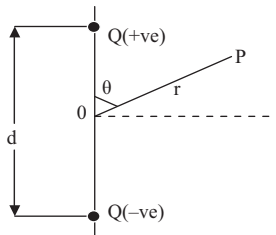


Fig. 5.1

- Total potential at point p .

$$V = \frac{q}{4\pi\epsilon_0} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

- If $r \gg d$ then

$$r_2 - r_1 = d \cos \theta; \quad r_1, r_2 = r$$

$$V = \frac{q}{4\pi\epsilon_0} \cdot \frac{d \cos \theta}{r^2} = \frac{P \cos \theta}{4\pi\epsilon_0 r^2}$$

where, $P = dq$ is dipole moment.

- If $\theta = 90^\circ$, then no work is to be done for bringing a charge from infinity along the perpendicular bisector.

Gauss's Law for Dielectric

- $D = \epsilon_0 E + P$
where, P = Polarization.
- Polarization is linearly related to the electric field E for isotropic materials in which E and P are always proportional.
 $P \propto E$

$$P = \epsilon_0 X_e E$$

$$D = \epsilon_0 E + \epsilon_0 X_e E = \epsilon_0 E(1 + X_e) = \epsilon E$$

$$\epsilon = \epsilon_0(1 + X_e)$$

where, ϵ = called as permittivity

X_e = electric susceptibility.

- $\epsilon_r = 1 + X_e$ called as relative permittivity

$$\epsilon = \epsilon_0 \epsilon_r$$

$$\text{Polarization} = \frac{\text{Dipole moment}}{\text{unit volume}}$$

5.3 MAGNETOSTATION

Force on a Charged Particle in a Magnetic Field

For a particle with charge q moving with a velocity $\vec{V}$ in a uniform magnetic field, the force is given by

$$\vec{F} = q\vec{V} \times \vec{B}$$

Since it is a vector product the force experienced is perpendicular to both velocity and magnetic field.

As the force is perpendicular to the velocity, no work is actually done by this force.

Let there be a magnetic field going into the paper. A charge q is projected with speed $\vec{V}$ in the field. The force is in the direction perpendicular to both V and B and as such deflects the particle in a circular path. If r be radius, then $qVB = \frac{mV^2}{r}$ or $r = \frac{mV}{qB}$

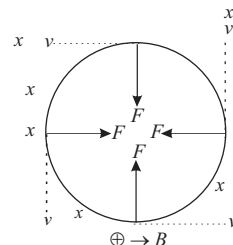


Fig. 5.2

Magnetic Force on a Wire Carrying Current

For a wire of length dl carrying a uniform current i and placed in a steady magnetic field is given by

$$d\vec{F} = i d\vec{l} \times \vec{B}$$

where, $d\vec{l}$ denoted the length in the direction of current:

If there is a loop having n turns and carrying a current i in a uniform magnetic field, the torque experienced by the loop is given by

$$\vec{T} = ni\vec{A} \times \vec{B}$$

where, $\vec{A}$ is the area vector and $ni\vec{A}$ is a magnetic dipole moment.

Magnetic Field Produced by a Current

Biot Savart Law

The magnetic field at a point P , due to a current element is given

$$\text{by } d\vec{B} = \frac{1}{4\pi\epsilon_0 C^2} \frac{id\vec{l} \times \vec{r}}{r^3} \text{ Tesla}$$

Where, C is the velocity of light.

The quantity $\frac{1}{\epsilon_0 C^2}$ is written as

$\mu_0 \rightarrow$ permeability of free space.

$$\text{Thus } d\vec{B} = \frac{\mu_0 i}{4\pi} \frac{d\vec{l} \times \vec{r}}{r^3}$$

For a straight wire carrying current I , the magnetic field at a point P at a distance d from it is given by

$$\vec{B} = \frac{\mu_0 i}{4\pi d} (\cos\theta_1 - \cos\theta_2)$$

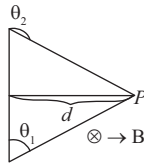


Fig. 5.3

Thus for m infinite wire $\theta_1 = 0$, $\theta_2 = \pi$. So the field is effectively $B = \frac{\mu_0 i}{2\pi d}$

Force Between Parallel Currents

The force between two parallel wires carrying current i_1 and i_2 is given by

$$dF = dl \frac{\mu_0 i_1 i_2}{2\pi r}$$

where dl is a small length of wire. The force is attractive for wires carrying current in the same direction and repulsive for the opposite.

Field in a Circular Loop

For a circular loop carrying current i and having a radius d , the magnetic field produced by the current at the centre is given by

$$B = \frac{\mu_0 i}{2d} \text{ Tesla .}$$

Ampere's Law

For a given uniform magnetic field, the circulation $\oint \vec{B} \cdot d\vec{l}$ of the resultant field, along a closed plane curve is equal to μ_0 times the total current crossing the area bounded by closed curve provided the electric field inside the loop remains constant.

$$\text{i.e., } \oint \vec{B} \cdot d\vec{l} = \mu_0 i$$

$$\text{or } \oint \vec{H} \cdot d\vec{l} = i$$

Where, $\vec{H}$ is the magnetic field intensity.

Ampere's law gives a very efficient method of calculating the magnetic field for symmetric current distributions.

Magnetic Field Due to a Solenoid

A solenoid is a wire wound closely in the form of a helix. Generally, the length of the solenoid is large as compared to its cross sections.

The field inside at the internal point is very large and is given by

$$B = \frac{\mu_0 n i}{\ell}$$

where, n is the number of turns and ℓ is the length.

The field at an external point is zero, as the field produced by the wires adjacent cancel each other.

Electromagnetic Induction: Faraday's Law

When ever the flux of a magnetic field passes through the area bounded by a closed conducting loop changes, an emf is produced in the loop. The emf is given by

$$E = \frac{d\phi}{dt}$$

where, ϕ is the total flux of magnetic field through the area and

$$\phi = \int \vec{B} \cdot d\vec{s}.$$

The flux may be changed in a number of ways-by changing the magnetic field, by changing the area or by changing the angle between area vector $d\vec{s}$ and magnetic field.

The direction of the induced current, as seen from the equation is such that it opposes the very charge that has induced it. This is popularly known as **Lenz's law**.

Biot Savart Law

- $B = \frac{\mu_0}{4\pi} \int \frac{dl \times \vec{r}}{r^2}$
- $\nabla \cdot B = 0$ known as Maxwell's II equation.

Ampere's Law

It states that the magnetic field strength H around a closed path is equal to the current enclosed by the path.

$$\oint H \cdot dl = I \text{ amperes.}$$

Ampere's Law in Integral Form

$$\oint (\nabla \times H) \cdot ds = I = \oint H \cdot dl = \iint J \cdot ds$$

$$\nabla \cdot E = [\rho/\epsilon_0]; \nabla \times E = 0$$

$$\nabla \cdot B = 0; \nabla \times B = \mu_0 J$$

Continuity equation

$$\nabla \cdot J = [-\partial\rho/\partial t]$$

ρ = volume charge density

- $\nabla \cdot (\sigma E) + [\partial\rho/\partial t] = 0$
 $\nabla \cdot (\sigma E) + [\partial\rho/\partial t] = 0$, but $\nabla \cdot E = [\rho/\epsilon_0]$
 $\sigma \cdot [\rho/\epsilon_0] + [\partial\rho/\partial t] = 0$, on solving we have
 $\rho = \rho_0 e^{\frac{-\sigma t}{\epsilon_0}}$
- **Relaxation time** for material: $[\epsilon_0/\sigma]$.

5.4 TIME VARYING FIELDS AND MAXWELL'S EQUATION

Time varying magnetic fields produce electric field

$$\nabla \times E = [-\partial B/\partial t].$$

Energy Stored in Magnetic Field

$$W_m = [1/2] L I^2.$$

Force Between two Parallel Wires

$$F = \frac{\mu_0 \cdot I_1 I_2}{2\pi d}$$

where, I_1 and I_2 are current flowing through two wires

d = is separation between wires

F = force per unit length.

Displacement Current

$$J_D = \frac{\delta D}{\delta t} = \epsilon \frac{\partial E}{\partial t}$$

$$J_C = \sigma E$$

where, J_C = conduction current density

J_D = displacement current density

$$\nabla \times \vec{H} = \sigma E + \frac{\partial D}{\partial t} = \sigma E + j\omega\epsilon E$$

$$\nabla \times \vec{H} = (\sigma + j\omega\epsilon) E$$

Important points to be remembered.

Equation	Statement
1. $\nabla \times \vec{H} = \sigma E + \epsilon [\partial E/\partial t]$	(modified Ampere's law) Magnetic moment force around a closed path produces conduction current and displacement current
2. $\nabla \times \vec{E} = [-\partial B/\partial t]$	(modified Faraday's law) Electromotive force over a closed path is equal to the time derivative to the magnetic.
3. $\nabla \cdot \vec{E} = [\rho/\epsilon]$	(Gauss law) Total electric displacement through a surface enclosing a volume is equal to the charge in the volume
4. $\nabla \cdot \vec{B} = 0$	Net magnetic flux in a closed surface is zero. Also indicates there can be no monopole.

- Relations of field components along with material properties.

$$D = \epsilon E$$

$$B = \mu H$$

$$J = \sigma E$$

- For charge free region, we have the following Maxwell's equation

$$\nabla \cdot D = 0$$

$$\nabla \cdot B = 0$$

$$\nabla \times E = [-\partial B/\partial t]$$

$$\nabla \times H = [\partial D/\partial t]$$

The Uniform Plane Wave

To consider wave propagation in free space, Maxwell's equation may be written in terms of $\vec{E}$ and $\vec{H}$ only.

For free space

$$\nabla \times \vec{H} = \epsilon \frac{\partial \vec{E}}{\partial t}$$

$$\nabla \times \vec{E} = -\mu_0 \frac{\partial \vec{H}}{\partial t}$$

$$\nabla \cdot \vec{E} = 0$$

$$\nabla \cdot \vec{H} = 0$$

Let us solve these four equations for a special case, a sinusoidally varying fields i.e., given the vector fields

$$\vec{E}_x = E_x \vec{a}_x, E_y = E_y \vec{a}_y, E_z = E_z \vec{a}_z \quad E = (x, y, z) \cos(\omega t + \psi)$$

5.8 ■ Electromagnetic Theory

Where, $E(x, y, z)$ is a real function of x, y and z but not of time.

We thus have $E_x = \text{Re}[E(x, y, z) e^{j\omega t}]$

Identifying the phasor $E_{xs} = E(x, y, z) e^{j\omega}$.

Thus, $E_x = \text{Re}(E_{xs} e^{j\omega t})$

Wave Propagation Through Dielectrics

For a dielectric medium, the propagation constant is a complex quantity given by $\gamma = \alpha + j\beta$

The Maxwell's solution will then be $E_x = E_0 e^{-\alpha z} \cos(\omega t - \beta z)$
 α is called the attenuation constant and is measured in nepers per meter (Np/m). Greater the value of α , the faster the wave amplitude dies down.

The phase velocity is given by $V_p = \frac{\omega}{\beta}$

- **Wave Equation** or Helmholtz Equations:

$$\nabla^2 H = \mu \epsilon \frac{\partial^2 H}{\partial t^2}$$

$$\nabla^2 E = \mu \epsilon \frac{\partial^2 E}{\partial t^2}$$

- Propagation constant (γ)
- Real part is called attenuation constant (σ)
- Imaginary part is called phase constant (β)

$$\gamma = \alpha + j\beta$$

- For a perfect dielectric

$$\gamma = \pm j\omega \sqrt{\mu_0 \epsilon_0} \text{ and } \alpha = 0$$

- $\beta = \omega \sqrt{\mu_0 \epsilon_0}$

$$\text{also, we have } \beta = \frac{2\pi}{\lambda}$$

$$\frac{\omega}{\beta} = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = C$$

- For conducting medium

$$\nabla^2 H = \gamma^2 H; \quad \nabla^2 E = \gamma^2 E$$

where, $\gamma^2 = j\omega\mu(\sigma + j\omega\epsilon)$ is propagation constant

$$\alpha = \omega \sqrt{\left(\frac{\mu\epsilon}{2}\right) \sqrt{1 + \frac{\sigma^2}{\omega^2 \epsilon^2}}}$$

$$\beta = \omega \sqrt{\left(\frac{\mu\epsilon}{2}\right) \sqrt{1 + \frac{\sigma^2}{\omega^2 \epsilon^2}}}$$

- $\nabla \times H = \sigma E + j\omega\epsilon E$
- First term is conduction current and second term is displacement current.
- Divide line between conductor and insulator is $[\sigma/\omega\epsilon] = 1$
- **Loss tangent** $\tan \theta = [\sigma/\omega\epsilon]$

Loss Tangent

The loss tangent for a dielectric is given by $\tan \theta = \frac{\sigma}{\omega \epsilon}$

Now for a dielectric α is approximately given by $\alpha = \frac{\sigma}{2} \sqrt{\frac{\mu}{\epsilon}}$.

Thus the greater is conductivity σ , the greater is α and so the greater is the loss. Hence the ratio $\frac{\sigma}{\omega \epsilon}$ is called loss tangent.

- For dielectric or poor conductor

$$\sigma \ll \omega \epsilon$$

$$\alpha = [\sigma/2] [\mu/\epsilon]$$

$$\beta = \omega \sqrt{\mu \epsilon}$$

- For a good conductor $\sigma \gg \omega \epsilon$

$$\gamma = \left(\frac{\omega \mu \sigma}{2}\right)^{1/2} (1 + j1); \quad \alpha = \beta = \sqrt{\frac{\omega \mu \sigma}{2}}$$

Power Flow and Poynting Vector

The electromagnetic power flow is given by Poynting vector which states that the power per unit area is:

$$P = \frac{1}{2} \text{Re}(E \times H^*)$$

where, H denotes complex conjugate.

Thus with electric and magnetic field perpendicular to each other and to the direction of propagation. So by Poynting's theorem, we have the power flow in the direction of propagation.

Thus for electric field $E = E_0 e^{-\alpha z} \cos(\omega t - \beta z)$ and magnetic field given by $H = \left\{ H_0 e^{-\alpha z} \cos(\omega t - \beta z) \right\}_{\eta}$, the Poynting vector is $\frac{E_0^2}{|\eta|} e^{-2\alpha z} \cos(\omega t - \beta z - \phi)$

Here $n = |\eta| e^{j\phi}$.

Propagation in Good Conductor

For a good conductor, the attenuation and propagation constants are given approximately by

$$\alpha = \beta = \sqrt{\pi f \sigma \mu}$$

Thus, $E_x = E_0 e^{\sqrt{\pi f \sigma \mu} z} \cos(\omega t - \sqrt{\pi f \sigma \mu} z)$. Now the power is given as $\frac{E_0^2}{|\eta|} e^{-2\sqrt{\pi f \sigma \mu} z} \cos \theta$.

Thus for good conductor, σ is very large and so attenuation constant is very high leading to decay of magnitude of electric field at a fast rate. Thus at a distance $Z = \frac{1}{\sqrt{\pi f \sigma \mu}}$, the electric field decreases to $e^{-1} = 0.368$ of its initial value. This distance is

called the **skin depth**. It determines to how much depth the wave penetrates in a good conductor. Thus greater is the frequency, lesser is the skin depth and the field gradually decays at small distance from the surface.

Depth of Penetration or Skin Depth

Defined as the distance it takes to reduce the amplitude to $(1/e)$, about 37%

$$\delta = \left[\frac{1}{\alpha} \right] = \sqrt{\frac{2}{\omega\mu\sigma}}$$

- So, the depth of penetration for good conductor decreases with increasing frequency.
- In a lossy conducting media, characteristic impedance

$$\eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\epsilon}}$$

- For $\sigma \gg \omega\epsilon$ $\eta = \sqrt{\frac{j\omega\mu}{\sigma}} \angle 45^\circ$
 - For $\sigma \ll \omega\epsilon$ $\eta = \sqrt{\frac{\mu}{\epsilon}}$
 - There is no field in the direction of propagation.
 - The fields E and H are mutually perpendicular.
 - Ratio of electric field strength to magnetic field strength is η , called **intrinsic impedance**.
 - The two fields are also perpendicular to the direction of propagation.
- Free space impedance $\eta = 120\pi \approx 377\Omega$.

5.5 BOUNDARY VALUE PROBLEMS AND SOLUTIONS

Boundary conditions

1. The tangential components of electric fields of two media are equal at the boundary surface where they meet i.e., $E_{t1} = E_{t2}$
2. The magnetic fields of two media have their tangential components equal at the boundary surface where they meet i.e., $H_{t1} = H_{t2}$. When $\vec{K}$ is the linear current, density at the surface is zero.
3. The normal components of the magnetic flux density at the boundary surface are equal i.e., $\vec{B}_{N1} = \vec{B}_{N2}$
4. The difference between the normal components of electric flux density at the boundary surface is equal to the surface charge density at the surface.

$$D_{n1} = D_{n2} = \rho_s$$

- Tangential component of E is continuous or

$$E_{t1} = E_{t2} \text{ and } \frac{D_{t1}}{\epsilon_{r1}} = \frac{D_{t2}}{\epsilon_{r2}}$$

- Normal components of D are equal where, $\rho_s = 0$; $D_{n1} = D_{n2}$

Refraction of Electric Vector

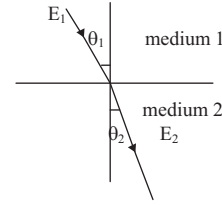


Fig. 5.4

$$\vec{D}_{n1} = \vec{D}_{n2}$$

$$D_1 \cos \theta_1 = D_2 \cos \theta_2$$

$$\frac{D_1}{D_2} = \frac{\cos \theta_2}{\cos \theta_1}$$

$$E_1 \sin \theta_1 = E_2 \sin \theta_2$$

$$\frac{E_1}{E_2} = \frac{\sin \theta_2}{\sin \theta_1}$$

$$\frac{D_1}{D_2} = \frac{\epsilon_{r1}}{\epsilon_{r2}} \cdot \frac{E_1}{E_2}$$

$$\frac{\cos \theta_2}{\cos \theta_1} = \frac{\epsilon_{r1}}{\epsilon_{r2}} \cdot \frac{\sin \theta_2}{\sin \theta_1} \text{ and } \frac{\tan \theta_2}{\tan \theta_1} = \frac{\epsilon_{r2}}{\epsilon_{r1}}$$

Wave Polarization

The wave polarization is defined as its electric field vector orientation as a function of line at a fixed position in space. Specifying electric field is sufficient as magnetic field can be readily found out from Maxwell's equation.

When E is in a fixed straight orientation, it is linearly polarized and can be oriented in any direction in x - y plane. This happens when $\vec{E}_x$ and $\vec{E}_y$ are in the same phase and E can be represented by $E_s = (E_{x0}\vec{a}_x + E_{y0}\vec{a}_y)e^{-\alpha z}e^{-j\beta z}$

Now, when there is a phase lag between the $\vec{E}_x$ and $\vec{E}_y$ components, the resultant electric field rotates in an elliptic path in the x - y plane and is elliptically polarized.

However, when the phase lag is $\frac{\pi}{2}$ and both $\vec{E}_x$ and $\vec{E}_y$

components are equal in magnitude then

$E_s = E(\vec{a}_x + j\vec{a}_y)e^{-j\beta z}e^{-\alpha z}$, then the resultant electric field rotates in a circular fashion and is said to be $E_x = E_0e^{\sqrt{\pi f \sigma \mu} z} \cos(\omega t - \sqrt{\pi f \sigma \mu} z)$ circularly polarized.

The wave exhibits left **circular polarization** when orienting the left hand with the thumb in the direction of propagation, the fingers curl in the direction of rotation. It is given by $\vec{E} = E_0[\cos(\omega t)\vec{a}_x - \sin(\omega t)\vec{a}_y]$

Similarly, the case of right circularly polarized wave

$$E = E_0[\cos(\omega t)\vec{a}_x + \sin(\omega t)\vec{a}_y]$$

Plane Wave Propagation in General Direction

The electric field propagating in a general direction in the x - y plane is given by $\vec{E}_s = E_0 e^{-jkr}$

$$\text{Where, } \vec{K} = k_x \vec{a}_x + k_y \vec{a}_y$$

The angle of propagation with respect to x -axis is

$$\theta = \tan^{-1} \left(\frac{k_y}{k_x} \right)$$

$$\text{The wavelength in the direction of propagation is } \frac{2\pi}{\sqrt{K_x^2 + K_y^2}}$$

$$\text{and phase velocity is } \frac{\omega}{\sqrt{K_x^2 + K_y^2}}$$

$$\text{And wavelength and velocity in } x\text{-directions are } \frac{2\pi}{K_x} \text{ and } \frac{\omega}{K_x} \text{ respectively.}$$

Refraction

The condition for refractions are $\eta_1 \sin \theta_1 = \eta_2 \sin \theta_2$ where η is the refractive index with $\eta_1 = \sqrt{\epsilon_1}$ and $\eta_2 = \sqrt{\epsilon_2}$ and θ_1 and θ_2 are the angles of incidence and refraction.

H or P-plane Polarized Wave

For a plane polarized, H field remains perpendicular to plane of propagation (TM wave). In this case the boundary conditions are

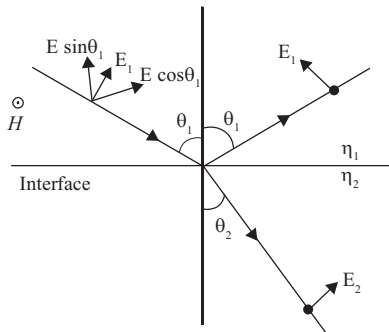


Fig. 5.5

$$E_{10}^+ \cos \theta_1 + E_{10}^- \cos \theta_1 = E_{20} \cos \theta_2 \text{ and}$$

$$H_{10}^+ + H_{10}^- = H_{20}^+$$

$$P = \frac{\eta_{2p} - \eta_{1p}}{\eta_{2p} + \eta_{1p}}$$

$$\text{where, } \eta_{2p} = \eta_2 \cos \theta_2 \text{ and}$$

$$\eta_{1p} = \eta_1 \cos \theta_1$$

E or S-plane Polarized Wave

For an S plane polarized wave or T.E. wave where $\vec{E}$ is perpendicular to plane of propagation the boundary conditions remain.

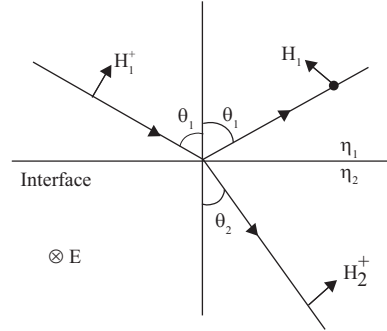


Fig. 5.6

$$E_{10}^+ + E_{10}^- = E_{20}^+ \text{ and}$$

$$H_{10}^+ \cos \theta_1 + H_{10}^- \cos \theta_1 = H_{20}^+ \cos \theta_2$$

$$\text{The reflection coefficient is } \Gamma = \frac{\eta_{2s} - \eta_{1s}}{\eta_{2s} + \eta_{1s}}$$

$$\text{where, } \eta_{2s} \rightarrow \eta_2 \sec \theta_2$$

$$\text{and } \eta_{1s} \rightarrow \eta_1 \sec \theta_1$$

Special Cases for P-plane Polarized Wave

1. Total Internal reflection

From Snell's law, we have $n_1 \sin \theta_1 = n_2 \sin \theta_2$. Now for **P-plane polarized** wave there arises a situation – for any wave travelling from a **denser medium** (greater value of ϵ) to a **rarer medium** (smaller value of ϵ), there exists a certain angle of incidence θ_1 (critical angle) such that if this angle is exceeded, the wave is not refracted into medium 2, but reflected totally in medium 1.

Thus for limiting case, we have when the wave is incident on critical angle, the refracted ray just grazes the interface. Thus $\theta_2 = 90^\circ$.

$$\text{So, we have } \eta_1 \sin \theta_c = \eta_2 \sin 90^\circ$$

$$\theta_c = \sin^{-1} \frac{\eta_2}{\eta_1}$$

2. Total transmission

Again for a **p-plane polarized** wave, there exists an angle θ_B (**Brewster's angle**) such that when a wave is incident at the interface at this angle, it is totally transmitted into 2nd medium with out any reflection in the first. The condition is

$$\tan \theta_B = \frac{\eta_2}{\eta_1}$$

Reflection Coefficient (τ)

$$\tau = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} = \frac{E_r}{E_i}$$

Where, E_r = reflected electric field
 E_i = incidence electric field
 η = refractive index.

Transmission coefficient (T)

$$T = \frac{E_T}{E_i} = \frac{2\eta_2}{\eta_1 + \eta_2}$$

where, E_T = transmitted electric field
 E_i = incidence electric field.

$$\text{Index of refraction } (\eta) = \frac{C}{V} = \sqrt{\frac{\epsilon\mu}{\epsilon_0\mu_0}}$$

$$= C\sqrt{\mu\epsilon}$$

$$\tau = \frac{\sqrt{\epsilon_1} - \sqrt{\epsilon_2}}{\sqrt{\epsilon_1} + \sqrt{\epsilon_2}}; \quad T = \frac{2\sqrt{\epsilon_1}}{\epsilon_1 + \epsilon_2}.$$

Critical Angle of Incidence

$$\theta_c = \sin^{-1}\left(\frac{\eta_1}{\eta_2}\right) = \sin^{-1}\left(\frac{\epsilon_2}{\epsilon_1}\right)$$

Brewster angle $\theta_{B\parallel}$ (Parallel Polarization): When there is no reflection and the incident angle at which this takes place is called *Brewster angle*. The Brewster angle is also known as the polarizing angle because an arbitrarily polarized incident wave will be reflected with only the component of E perpendicular to the plane of incidence. The Brewster effect is utilized in a laser tube where quartz windows are set at the Brewster angle to control polarization of emitted light. The Brewster angle is obtained by setting $\theta_i = \theta_{B\parallel}$.

When $T_{\parallel} = 0$.

$$\tan \theta_i = \tan \theta_{B\parallel} = \sqrt{\frac{\epsilon_2}{\epsilon_1}}.$$

Perpendicular Polarization

$$\tan \theta_i = \tan \theta_{B\perp} = \sqrt{\frac{\mu_2}{\mu_1}}$$

Wave passing from perfect dielectric to perfect conductor.

- For perfect conductor $\sigma_2 = \infty$
 $\eta_2 = 0$
 $\tau = -1$
- Group velocity $V_g = [C^2/V_p]$.

5.6 TRANSMISSION LINES

- The transmission line equation is

$$\frac{\partial^2 V}{\partial x^2} - (R + j\omega L)(G + j\omega C)V = 0$$

- The secondary parameters in terms of primary parameters are given by

$$Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

- Propagation constant

$$\gamma = [R + j\omega L](G + j\omega C)^{1/2} = \alpha + j\beta$$

where, α = attenuation constant

β = phase constant.

- For small losses

$$Z_o = \sqrt{\frac{L}{C}} \left\{ 1 + j \left(\frac{G}{2\omega C} - \frac{R}{2\omega L} \right) \right\}$$

- For lossless transmission line ($R = G = 0$)

$$Z_o = \sqrt{\frac{L}{C}} = R_o; \quad \alpha = 0$$

$$\beta = j\omega \sqrt{LC}$$

$$v = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}} \text{----- Velocity of propagation.}$$

- For distortion less transmission line

$$RC = LG$$

under this condition Z_o is real. This is called the Heaviside's condition for a distortion less line.

Terminated Transmission Line

- For lossy transmission line, input impedance is given by

$$Z_{in} = Z_o \left(\frac{Z_L + Z_o \tanh \gamma x}{Z_o + Z_L \tanh \gamma x} \right)$$

- For lossless transmission line

$$Z_{in} = Z_o \left(\frac{Z_L + jZ_o \tan \beta \ell}{Z_o + jZ_L \tan \beta \ell} \right)$$

Input impedance of a lossless transmission line for various lengths is given by

	$\beta = [2\pi/\lambda]$	
For $\ell = \lambda;$	$\tan [2\pi/\lambda] \cdot \lambda$	
$Z_{in} = Z_L$		
For $\ell = \lambda/2;$	$\tan [2\pi/\lambda] \cdot [\lambda/2];$	
$Z_{in} = Z_L$		
For $\ell = \lambda/4;$	$\tan [2\pi/\lambda] \cdot [\lambda/4]$	
	$= \tan [\pi/2]$	
$Z_{in} = [Z_o^2/Z_L]$		
For $\ell = \lambda/8;$	$Z_{in} = Z_o \left(\frac{Z_L + Z_o}{Z_o + Z_L} \right)$	

- When the line is open circuited ($Z_L = \infty$)

$$Z_{in} = Z_{oc} = -j Z_o \cot \beta \ell$$

- When the line is short circuited ($Z_L = 0$)

$$Z_{in} = Z_{sc} = j Z_o \tan \beta \ell$$

- Thus, $Z_{oc} \cdot Z_{sc} = Z_o^2$.

Reflection Coefficient and VSWR

When the load is not matched to the characteristic impedance of the line, then the wave is reflected back from Z_L .

- (a) Reflection coefficient for voltage

$$K = \left(\frac{Z_L - Z_o}{Z_L + Z_o} \right)$$

- (b) Reflection coefficient for current

$$K' = \left(\frac{Z_o - Z_L}{Z_o + Z_L} \right) = -K$$

- (c) Transmission coefficient for voltage

$$T = \left(\frac{2Z_L}{Z_o + Z_L} \right) = 1 + K$$

- (d) Transmission coefficient for current

$$T' = \left(\frac{2Z_L}{Z_o + Z_L} \right) = 1 + K'$$

- (e) Voltage standing wave ratio is given by

$$VSWR(s) = \frac{V_{\max}}{V_{\min}} = \frac{I_{\max}}{I_{\min}} = \frac{1 + |K|}{1 - |K|} \quad \text{and}$$

$$|K| = \frac{VSWR - 1}{VSWR + 1}.$$

Transmission Line Character for Different Load

(a) For matched line ($Z_L = Z_o$)	$K = 0$,	VSWR = 1
(b) For open circuited line ($Z_L = \infty$)	$ K = 0$,	VSWR = ∞
(c) For short circuited line ($Z_L = 0$)	$ K = 0$,	VSWR = ∞
(d) For inductive load ($Z_L = jX_L$)	$K = 1 \angle 90^\circ$,	VSWR = ∞
(e) For capacitive load ($Z_L = -jX_C$)	$K = 1 \angle -90^\circ$,	VSWR = ∞

Stub Matching

Although single lumped inductors or capacitors can match the transmission line, it is more common to use the susceptive properties of short circuited sections of transmission lines. Short circuited sections are preferable to open circuited ones because a good open radiate is easier to obtain than a good open circuit.

For a lossless line with $Y_s = Y_o$, maximum power transfer requires $Y_{11} = Y_o$ where Y_{11} is the total admittance of the line and stub looking to the right at point 1-1. The stub must be located at that point on the line where the real part of the admittance looking reward the load, Y_o in a normalized Y_{11} must be in the form

$$Y_{11} = Y_d \pm Y_s = 1$$

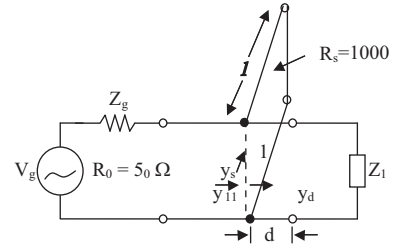


Fig. 5.7

Single Stub Matching

If the stub has the same characteristic impedance as that of the line. Otherwise

$$Y_{11} = Y_d \pm Y_s = Y_o$$

The stub length is then adjusted so that its susceptance just cancels out the susceptance of the line at the junction.

The input impedance of an open circuited or short circuited lossless line is purely reactive. Such a section is usually connected across the line at convenient point and cancels the reactive part of impedance at this point seen looking towards the load. Such a section is called impedance matching stub.

Usually, the length of matching stub is kept within a quarter wavelength so that the stub remains practically lossless at all high frequency.

A short circuit stub of length less than $[\lambda/4]$ offers inductive reactance at the input while an open circuit stub of length less than $[\lambda/4]$ offers capacitive reactance at the input.

Smith Chart

Graphical Methods: Smith Chart

Smith chart provides an easy way of solving transmission line problems without solving complex equations. The basis of smith chart is as follows:

$$P = \frac{Z_L - Z_o}{Z_L + Z_o} \quad \text{Impedance here will be normalized with}$$

respect to Z_o .

$$Z_L = r + jx = \frac{Z_L}{Z_o} = \frac{R_L + jX_L}{Z_o} \quad \text{and thus}$$

$$\Gamma = \frac{Z_L - 1}{Z_L + 1}$$

$$\text{Now} \quad \Gamma = P_r + jP_i$$

$$\therefore \quad r + jx = \frac{1 + P_r + jP_i}{1 - P_r - jP_i}$$

Thus we get the constant resistance and constant reactance curve on P_r and P_i axis as

$$\left(P_r - \frac{r}{r+1}\right)^2 + P_i^2 = \left(\frac{1}{1+r}\right)^2 \quad (1)$$

$$(P_r - 1)^2 + \left(P_i - \frac{1}{x}\right)^2 = \left(\frac{1}{x}\right)^2 \quad (2)$$

The first equation describes a family of constant resistance circles. For $r = 0$, it is centered at origin with radius = 1

The second equation describes a family of constant reactance circle. These circles are as shown.

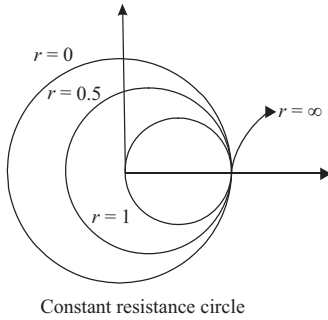


Fig. 5.8

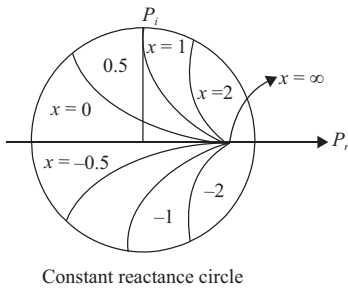


Fig. 5.9

$$\text{We have } Z_{in} = \frac{1 + Pe^{-j2\beta\ell}}{1 - Pe^{-j2\beta\ell}} = \frac{1 + |P|e^{j(\phi - 2\beta\ell)}}{1 - |P|e^{j(\phi - 2\beta\ell)}}$$

Thus, we see that in the Smith chart, as we move clockwise we are actually decreasing the angle and thus moving towards the generator from load end. For a rotation of 180° in the clockwise direction, we are moving a distance of $\frac{\lambda}{4}$ distance from load.

Information containing maxima and minima can also be obtained from Smith chart. This is because a maxima occurs at those point where Z_{in} is a pure resistance and $Z_{in} > Z_0$. If $Z_{in} < Z_0$ and Z_{in} is pure resistance, minima occurs. We note that standing wave ratio produced by resistive load R_L is either $\frac{R_L}{R_0}$ or $\frac{R_0}{R_L}$ whichever is greater. This value of VSWR may be read directly as the value of r at the intersection of $|P|$ circle and r axis, $r > 1$.

The characteristics of the Smith chart are summarized as follows:

1. The constant r and constant x loci form two families of orthogonal circles in the chart.
2. The constant r and constant x circles all pass through the point $(\Gamma_r = 1, \Gamma_i = 0)$.
3. The upper half of the diagram represents $+jx$.
4. The lower half of the diagram represents $-jx$.
5. For admittance the constant r circles become constant g circles, and the constant x circles become constant susceptance b circles.
6. The distance around the Smith chart once is one half wavelength $(\lambda/2)$.
7. At a point of $Z_{min} = 1/\rho$ there is a V_{min} on the line.
8. At a point of $Z_{max} = \rho$, there is a V_{max} on the line.
9. The horizontal radius to the right of the chart center corresponds to V_{max} , I_{min} , Z_{max} , and $\rho(SWR)$.
10. The horizontal radius to the left of the chart center corresponds to V_{min} , I_{max} , Z_{min} , and $1/\rho$.
11. Since the normalized admittance y is a reciprocal of the normalized impedance z , the corresponding quantities in the admittance chart are 180° out of phase with those in the impedance chart.
12. The normalized impedance or admittance is repeated for every half wavelength of distance.
13. The distances are given in wavelength toward the generator and also towards the load.

The magnitude of the reflection coefficient is related to the standing wave ratio by the following expression

$$|\Gamma| = \frac{\rho - 1}{\rho + 1}$$

A Smith chart or **slotted line** can be used to measure a standing wave pattern directly and then the magnitude of the reflection coefficient, reflected power transmitted power, and the load impedance can be calculated from it.

5.7 BASICS OF WAVE GUIDE AND RESONATOR

A hollow metallic tube of uniform cross section for transmitting electromagnetic wave by successive reflection from the inner walls of the tube is called a **wave guide**.

Principles of Wave Guide

We have seen a two conductor co-axial transmission line used for transmission of electromagnetic power at low frequency. But at high frequencies, the electric fields attenuate very fast due to skin effect and thus there is a considerable loss of power. Thus, we resort to waveguides which are hollow metallic structures with the guide walls, having $j_c = \infty$ (perfect conductor) and dielectric filled hollow space (perfect dielectric). It is further supposed that $\rho = 0$ (no free charge) in the dielectric.

5.14 ■ Electromagnetic Theory

Just as a transverse electromagnetic (TEM) wave travels through a transmission line, either transverse magnetic (TM) or transverse electric (TE) waves travel through a waveguide but no TEM wave travels in a wave guide. There is either a component of electric field or magnetic field in the direction of the waveguide.

Transverse Electric (TE) Wave

Here $\vec{E}_x$ and $\vec{E}_y$ exist and $\vec{H}_x$, $\vec{H}_y$ and $\vec{H}_z$ exist assuming wave propagation to be in the +Z direction.

The propagation constant in the Z direction is given by

$$\beta = \omega \sqrt{\mu \epsilon} \sqrt{1 - \left(\frac{f_c}{f}\right)^2}$$

$\omega \rightarrow$ frequency in rad/sec.

The guided wavelength $\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$

And phase velocity is given by $V_p = \frac{C}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$

The impedance is given by $\frac{\eta}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$

where η in the free space impedance and $\eta = 377 \Omega$

Here a and b denote the width and height of the waveguide m and n denote the number of half wavelengths along a and b directions respectively.

Thus TE_{mn} denote transverse electric wave with m half waves along a and n half waves along b (assume $a > b$) f_c is the cut-off for a particular mode. Thus for a TE_{mn} wave in a dielectric of relative permittivity

$$f_c = \frac{C}{2\sqrt{\epsilon_r}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

The mode with the lowest cut off frequency is called the **dominant mode**. Since $a > b$ the dominant mode is TE_{10} mode with the cut-off frequency being

$$f_c = \frac{C}{2\sqrt{\epsilon_r}} \sqrt{\left(\frac{1}{a}\right)^2 + \left(\frac{0}{b}\right)^2} = \frac{C}{2a\sqrt{\epsilon_r}}$$

Transverse Magnetic (TM) Wave

The equation derived for TE wave also apply for TM waves and only impedance differ. The wave impedance is given by

$n\sqrt{1 - \left(\frac{f_c}{f}\right)^2}$ for a TM wave.

Two modes having the same cut-off frequency are called degenerate mode. Thus TE_{mn} and TM_{mn} ($m \geq 1, n \geq 1$) are called

degenerate modes with $f_c = \frac{C}{2\sqrt{\epsilon_r}} \left[\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 \right]^{\frac{1}{2}}$

A TM_{10} for TM_{01} mode does not exist as putting $n = 0$, or $m = 0$ we have $\vec{E}_z = 0$ and thus the waves reduce to TE_N waves which is not possible.

Power Transmitted in a Lossless Wave Guide

The power transmitted is given using the general wave equation of poyinting

$$\vec{P}_z = \frac{1}{2} \text{Re} \iint_A \vec{E}_r \times \vec{H}_r \cdot \vec{a}_z ds$$

Substituting the field components and writing $Ag = ab$, we obtain for the dominant mode of a lossless rectangular waveguide.

$$P_{z10} = \eta |H_{10}|^2 \left(\frac{2a}{\lambda_0}\right) \left(\frac{2a}{\lambda_0}\right) Ag$$

Now as $|E_0| = \eta_0 \left(\frac{2a}{\lambda_0}\right) A_{10}$ it is useful to write P_z as

$$P_z = \frac{|E_{10}|^2 A_z}{4\eta_0} \sqrt{1 - \left(\frac{f_{c10}}{f}\right)^2} = \frac{|E_{10}|^2 Ag}{4\eta_{TE0}}$$

Microwave Excitation

Consider a microwave excitation cavity of dimension a , b and c . The cut-off frequency for a TE_{mnp} or TE_{mnp} is given by

$$f_c = \frac{c}{2\sqrt{\epsilon_r}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{c}\right)^2}$$

where, ϵ_r is the relative permittivity of the dielectric inside the guide.

The factor of a microwave resonant cavity is defined as

$$Q = 2\pi \frac{\text{Energy stored in cavity}}{\text{Energy dissipated per cycle}} = \frac{\omega \mu (\text{total volume})}{2Rg (\text{Surface area})}$$

Rectangular Wave Guide

Consider the rectangular waveguide shown in the figure. Let us assume that the waveguide is filled with a source-free ($\rho_v = 0, J = 0$) lossless dielectric material ($\sigma \approx 0$) and its walls are perfectly conducting ($\sigma_c \approx \infty$). From solution of Maxwell's equation i.e.,

$$\nabla^2 E_s - \gamma^2 E_s = 0 \text{ and}$$

$$\nabla^2 H_s - \gamma^2 H_s = 0$$

As usual, if we assume that the wave propagates along the waveguide in the + z-direction, the multiplicative constant $c_s = 0$ because the wave has to be finite at infinity [i.e., $E_{zs}(x, y, z = \infty) = 0$].

Hence equation is reduced to

$$E_{zs}(x, y, z) = (A_1 \cos k_x x + A_2 \sin k_x x) \\ (A_3 \cos k_y y + A_4 \sin k_y y) e^{-\gamma z}$$

where, $A_1 = c_1 c_6$, $A_2 = c_2 c_6$ and so on. By taking similar steps, we get the solution of the z-component of equation (4) as

$$H_{zs}(x, y, z) = (B_1 \cos k_x x + B_2 \sin k_x x) \\ (B_3 \cos k_y y + B_4 \sin k_y y) e^{-\gamma z}$$

We can find the solution of Max Well's equation in form of (H_{xs}, H_{ys}, H_{zs}) and (E_{xs}, E_{ys}, E_{zs}) . Each represents different type of equation (field patterns or configuration). Each of these distinct field patterns is called a *mode*.

1. **TEM mode ($E_{zs} = 0 = H_{zs}$):** This is transverse Electromagnetic (TEM) Mode, in which both the E and H fields are transversed to the direction of wave propagation. All field components vanish for $E_{zs} = 0 = H_{zs}$. Consequently, we conclude that *rectangular wave guide cannot support TEM mode*.
2. **TE modes ($E_{zs} = 0, H_{zs} \neq 0$):** For this case, the remaining components (E_{xs} and E_{ys}) of the electric field are transversed to the direction of propagation a_z . Under this condition, fields are said to be in *transverse electric* (TE) modes.
3. **TM modes ($E_{zs} \neq 0, H_{zs} = 0$):** In this case, the H field is transversed to the direction of wave propagation. Thus we have *transverse magnetic* (TM) modes.
4. **HE modes ($E_{zs} \neq 0, H_{zs} \neq 0$):** This is the case when neither E nor H field is transversed to the direction of wave propagation. They are sometimes referred to as *hybrid* modes.

Propagation Constant

By substituting equation (19) into equation (9) we obtain the equation for propagation constant.

$$\gamma = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - k^2}$$

where, $k = \omega\sqrt{\mu\epsilon}$

and $\gamma = \alpha + j\beta$.

Case A, [cut-off]

$$\text{If } k^2 = \omega^2 \mu\epsilon = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$$

$$\gamma = 0. \text{ or } \alpha = 0 = \beta$$

The value of ω that causes this, is called *cut off angular frequency* ω_c

$$\omega_c = \frac{1}{\sqrt{\mu\epsilon}} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad (x)$$

Case B [evanescent]

$$\text{If } k^2 = \omega^2 \mu\epsilon < \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$$

$$\gamma = \alpha, \beta = 0$$

In this case, we have no propagation at all. These non-propagating or attenuating modes are said to be evanescent.

Case C

$$\text{If } k^2 = \omega^2 \mu\epsilon > \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$$

$$\gamma = j\beta, \alpha = 0$$

That is from equation (w) the phase constant β becomes

$$\beta = \sqrt{k^2 - \left(\frac{m\pi}{a}\right)^2 - \left(\frac{n\pi}{b}\right)^2}$$

This is the only case when propagation takes place because all field components will have the factor $e^{-\gamma z} = e^{-j\beta z}$

The cut-off frequency is the operating frequency below which attenuation occurs, and above which propagation takes place.

The waveguide therefore operates as a high-pass filter. The cutoff frequency is obtained from equation (x).

Or

$$f_c = \omega_c = \frac{1}{2\pi\sqrt{\mu\epsilon}} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$

$$f_c = \frac{u'}{2} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \quad (8)$$

When $u' = [1/\sqrt{\mu\epsilon}]$ = phase velocity of uniform plane waves in the loss less dielectric medium ($\sigma = 0, \mu, \epsilon$) filling the waveguide. The cut-off wavelength λ_c is given by

$$\lambda_c = \frac{u'}{f_c}$$

$$\lambda_c = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}} \quad (9)$$

From equation (8) and (9). That TM_{11} has the lowest cut off frequency (or the longest cut off wavelength) of all the TM modes. The phase constant in term of f_c as

$$= \omega \sqrt{\mu\epsilon} \sqrt{1 - \left(\frac{f_c}{f}\right)^2}; \quad \beta = \beta' \sqrt{1 - \left(\frac{f_c}{f}\right)^2}$$

5.16 ■ Electromagnetic Theory

where, $\beta' = [\omega/\mu'] = \omega\sqrt{(\mu\varepsilon)}$.

For evanescent mode can be expressed in term of f_c , namely

$$\gamma = \alpha = \beta' \sqrt{1 - \left(\frac{f_c}{f}\right)^2}.$$

The Phase Velocity u_p , and the wavelength in the guide are respectively given by

$$u_p = \frac{\omega}{\beta}; \quad \lambda = \frac{2\pi}{\beta} = \frac{u_p}{f}$$

The intrinsic wave impedance of the mode is given by

$$\eta_{TM} = \sqrt{\frac{\mu}{\varepsilon}} \sqrt{1 - \left(\frac{f_c}{f}\right)^2}$$

$$\eta_{TM} = [E_x/H_y] = [\beta/\omega\varepsilon] = \eta' \sqrt{1 - \left(\frac{f_c}{f}\right)^2}$$

where, $\eta' = \sqrt{(\mu/\varepsilon)}$ = Impedance of uniform plane wave.

TE Modes

$$H_{zs} = H_0 \cos\left(\frac{m\pi x}{a}\right) \cos\left(\frac{m\pi y}{b}\right) e^{-\gamma z}$$

f_c , λ_c , β , μ and λ . will be same as TM mode TE_{10} or TE_{01} depending on the value of 'a' and b, the guide. It is standard practice to

have $a > b$ so that $\frac{1}{a^2} < \frac{1}{b^2}$

$$f_{cTE0} = \frac{u'}{2a} < f_{cTE1} = \frac{u'}{2b}$$

This is called the dominant mode of wave guide.

$$\eta_{TE} = \frac{n'}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

where, $\eta' = \sqrt{\mu\varepsilon}$; η_{TE} , $\eta_{TM} = \eta'^2$.

$$f_c = \frac{1}{2\sqrt{\mu\omega}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

$$\beta_g = \sqrt{\frac{\omega}{\mu\varepsilon}} \sqrt{1 - \left(\frac{f_c}{f}\right)^2}$$

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}; \quad v_g = \frac{V_p}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

$$\eta_{TE} = \frac{n}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

Power Transmission

$$P_{tr} = \oint \mathbf{p} \cdot d\mathbf{s} = \oint [1/2] (\mathbf{E} \times \mathbf{H}^*) \cdot d\mathbf{s}$$

For a loss less dielectric, the time average power flow

$$P_{tr} = \frac{1}{2Z_R} \int_a |E|^2 da = [Z_{g/2}] \int_a |E|^2 da$$

where, z_g is wave impedance,

TE_{mn} modes

$$P_{tr} = \sqrt{1 - \left(\frac{f_c}{f}\right)^2} \int_0^b \int_0^a (|E_x|^2 + |E_y|^2) dx dy$$

$$P_{tr} = \frac{1}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}} \int_0^b \int_0^a (|E_x|^2 + |E_y|^2) dx dy$$

where, $\eta = \sqrt{\mu/\varepsilon}$ is the intrinsic in an unbounded dielectric.

Wave Propagation in the Guide:

$$\left. \begin{array}{ll} \text{Medium velocity} & (u') \\ \text{Phase velocity} & (u_p) \\ \text{Group velocity} & (u_g) \end{array} \right\}$$

$$\text{where, } u = \frac{1}{\sqrt{\mu/\varepsilon}}$$

u_p : Is the velocity at which loci of constant phase are propagated down the guide and given by

$$u_p = \frac{\omega}{\beta} = \frac{u'}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

$$u_p u_g = u'^2.$$

Cavity Resonator

When another conducting plate is kept at distance of multiple of $(\lambda_g/2)$ then the hollow space so formed can support a signal which bounces back and forth between the two conducting plates this results in resonance and the configuration so formed is called cavity resonators.

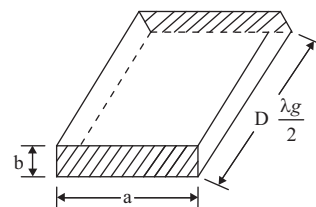


Fig. 5.10

$a \times b \times d \dots$ cavity resonators

$$f_0 = \frac{v_0}{2\pi} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{d}\right)^2}$$

Frequency of oscillation for $TE_{m,n,p}$

or $TM_{m,n,p}$

Dominant mode (TE_{101})

Circular Resonators

Case 1:

TE_{nmp} mode $h'_{11} = 1.841$

$$f_0 = \frac{v_0}{2\pi} \sqrt{\left(\frac{h'_{nm}}{a}\right)^2 + \left(\frac{p\pi}{d}\right)^2}$$

dominant mode TE_{11}

Case 2:

TM_{nmp} mode $h_{01} = 2.405$

$$f_0 = \frac{v_0}{2\pi} \sqrt{\left(\frac{h_{nm}}{a}\right)^2 + \left(\frac{p\pi}{d}\right)^2}$$

minimum frequency for TM mode TM_{101} .

5.8 ELEMENTS OF ANTENNA THEORY

A radio antenna may be defined as the structure associated with the region of transmission between a guided wave and a free space wave or vice versa.

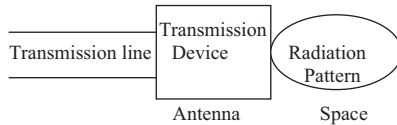


Fig. 5.11

Dipole

It is a combination of two equal and opposite charges separated by a small distance.

If electric charge = Q

Separation = d

Dipole moment = $Q.d$.

“A leaner conductor which at a given instant has a positive charge at one end and an equal but negative charge at the other end may act as a *dipole antenna*”.

Consider a transmission line connected to a dipole antenna as shown in the figure 5.12. The dipole acts as an antenna because it launches as free space wave.

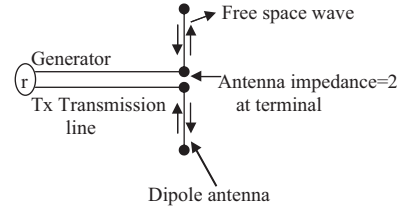


Fig. 5.12

“The dipole, exhibits simultaneously properties characteristic of an antenna, a transmission line and a resonator”.

Resonator

Resonator is a resonance circuit where electrical energy is converted into magnetic energy and back, which stores energy.

Radiation Intensity (U)

The power radiated from an antenna per unit solid angle is called the radiation intensity U (watts per Steradian or per square degree). The normalized power pattern of the previous section can also be expressed in terms of this parameter as the ratio of the radiation intensity $U(\theta, \phi)$, as a function of angle, to its maximum value.

Beam Efficiency

The (total) beam area Ω_A (or beam solid angle) consists of the main beam area (or solid angle) Ω_M plus the minor-lobe area (or solid angle) Ω_m .

Thus, $\Omega_A = \Omega_M + \Omega_m$.

The ratio of main beam area to the (total) beam area is called the beam efficiency ϵ_M . Thus,

$$\text{Beam efficiency} = \epsilon_M = \frac{\Omega_M}{\Omega_A} \text{ (dimensionless)}$$

The ratio of minor-lobe area (Ω_m) to the (total) beam area is called the stray factor thus

$$\text{stray factor, } \epsilon_m = \frac{\Omega_m}{\Omega_A}$$

It follows that, $\epsilon_M + \epsilon_m = 1$.

Directivity D

The directivity of an antenna is equal to the ratio of the maximum power density $P(\theta, \phi)_{\max}$ (Watts/m²) to its average value over a sphere as observed in the far field of an antenna. Thus,

$$D = \frac{P(\theta, \phi)_{\max}}{P(\theta, \phi)_{av}} \quad \text{Directivity from pattern}$$

The directivity is a dimensionless ratio ≥ 1 .

- Thus the directivity is the ratio of the area of a sphere (4π sr) to the beam Ω_A of the antenna.
- The smaller the beam area, the larger the directivity D .
- For an antenna that radiates over only half a sphere the beam area $\Omega_A = 2\pi$ sr and the directivity is

$$D = \frac{4\pi}{2\pi} = 2 (= 3.01 \text{ dBi})$$

Gain G

The gain G of an antenna is an actual or realized quantity which is less than the directivity D due to Ohmic losses in the antenna or its random (if it is enclosed). In transmitting, these losses involve power fed to the antenna which is not radiated but heats the antenna structure. A mismatch in feeding the antenna can also reduce the gain. The ratio of the gain to the directivity is the antenna efficiency factor.

Thus, $G = kD$

where, k = efficiency factor ($0 \leq k \leq 1$), dimensionless.

In many well-designed antennas, k may be close to unity. In practice, G is always less than D , with D its maximum idealized value.

Gain can be measured by comparing the maximum power density of the Antenna Under Test (AUT) with a reference antenna of known gain, such as a short dipole. Thus,

$$\text{Gain} = G = \frac{I_{\max}(AUT)}{P_{\max}(ref.ant)} \times G(ref.ant)$$

This means that the antenna radiates a power in the direction of the main-lobe maximum which is about 100 times as much as would be radiated by a non directional (isotropic) antenna for the same power input.

Resolution

The resolution of an antenna may be defined as equal to half the beam width between first nulls (BWFN/2), for example, an antenna whose pattern BWFN = 2° has a resolution of 1° and, accordingly, should be able to distinguish between transmitters on two adjacent satellites in the Clarke geostationary orbit separated by 1° . Thus, when the antenna beam maximum is aligned with one satellite, the first null coincides with the adjacent satellite.

Half the beam width between first nulls is approximately equal to the half-power beam width (HPBW) or $\frac{BWFN}{2} \approx HPBW$

We known that,

$$\Omega_A = \theta_{HP} \phi_{HP}$$

Antenna Aperture

The concept of aperture is most simply introduced by considering a receiving antenna. Suppose that the receiving antenna is a

rectangular electromagnetic horn immersed in the field of a uniform plane wave. Let the pointing vector, or power density, of the plane wave be S watts per square meter and the area, of the mouth of the horn be A square metre i.e., physical aperture of the horn, be A_p square metre. If the horn extracts all the power from the wave over its entire physical aperture, then the total power P absorbed from the wave is

$$P = \frac{E^2}{Z} A_p = S A_p \quad (\text{watt})$$

Thus, the electromagnetic horn may be regarded as having an aperture, the total power it extracts from a passing wave being proportional to the aperture or areas of its mouth.

But the field response of the horn is not uniform across the aperture A because E at the side walls must equal zero. Thus, the ratio of effective aperture to the physical aperture is the **aperture efficiency** ϵ_{ap} that is

$$\epsilon_{ap} = \frac{A_e}{A_p} \quad (\text{dimensionless}) \quad (2)$$

where, ϵ_{ap} = aperture efficiency.

Effective Height

The effective height h (metres) of an antenna is another parameter related to the aperture. Multiplying the effective height by the incident field E (volts per metre) of the same polarization gives the voltage V induced.

$$\text{Thus, } V = hE \quad (1)$$

Accordingly, the effective height may be defined as the ratio of the induced voltage to the incident field or

$$h = (V/E) \quad (\text{m}) \quad (2)$$

Consider, for example, a vertical dipole of length $\ell = [\lambda/2]$ immersed in an incident field E , as in figure (a). If the current distribution of the dipole were uniform, its effective height would be ℓ . The actual current distribution, however, is nearly sinusoidal with an average value $2/\pi = 0.64$ (of the maximum) so that its effective height $h = 0.64 \ell$. It is assumed that the antenna is oriented for maximum response.

Wave Polarization

Linear, elliptical and circular polarization:

Consider a plane wave travelling out of the page (positive z direction), as in the figure with the electric field at all times in the y direction. This wave is said to be linearly polarized (in the y direction). As a function of time and position, the electric field is given by:

$$E_y = E_2 \sin(\omega t - \beta z) \quad (1)$$

In general, the electric field of a wave travelling in the z direction may have both a y component and an x component, as suggested in figure (b).

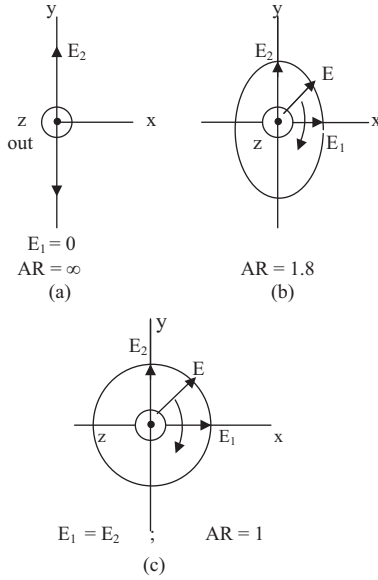


Fig. 5.13 (a) Linear Polarization (b) Elliptical Polarization, and (c) Circular polarization for left-circularly polarized wave approaching.

In this more general situation, with a phase difference δ between the components, the wave is said to be *elliptically polarized*. At a fixed value of z the electric vector E rotated as a function of time, the tip of the vector describing an ellipse called the *polarization ellipse*. The ratio of the major to minor axes of the polarization ellipse is called the *Axial Ratio (AR)*. Thus, for the wave figure (b), $AR = [E_2/E_1]$. Two extreme cases of elliptical polarization correspond to *circular polarization*, as in figure (c), and linear polarizations, as in figure (a). For circular polarization $E_1 = E_2$ and $AR = 1$, while for linear polarization $E_1 = 0$ and $AR = \infty$.

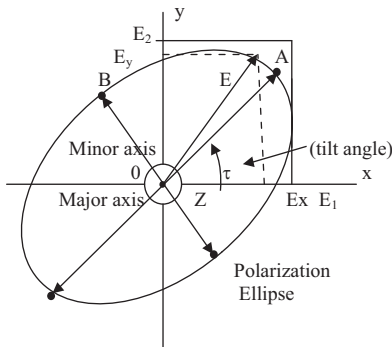


Fig. 5.14 (d) Polarization ellipse at tilt angle τ showing instantaneous components E_x and E_y and amplitudes (or peak values) E_1 and E_2

In the most general case of elliptical polarization, the polarization ellipse may have any orientation, as suggested in figure (d). The elliptically polarized wave may be expressed in terms of two

linearly polarized components, one in the x direction and one in the y direction. Thus, if the wave is travelling in the positive z direction (out of the page), the electric field components in the x and y directions are

$$E_x = E_1 \sin(\omega t - \beta z) \quad (2)$$

$$E_y = E_2 \sin(\omega t - \beta z + \delta) \quad (3)$$

Poynting Vector

In complex notation, the Poynting vector is

$$S = \frac{1}{2} E \times H^* \quad (1)$$

The average Poynting vector is the real part of (1), or

$$S_{av} = \text{Re } S = \frac{1}{2} \text{Re } [E \times H^*] \quad (2)$$

We can also write

$$S_{av} = \frac{1}{2} \hat{z} \frac{E_1^2 + E_2^2}{Z_0} = \frac{1}{2} \hat{z} \frac{E^2}{Z_0} \quad (Wm^{-2}) \quad (3)$$

where, $E = \sqrt{E_1^2 + E_2^2}$ is the amplitude of the total E field.

Example:

Elliptically polarized wave travelling in the positive z direction in air has x and y components as

$$E_x = 3 \sin(\omega t - \beta z) \quad (Vm^{-1})$$

$$E_y = 6 \sin(\omega t - \beta z + 75^\circ) \quad (Vm^{-1})$$

Find the average power per unit area conveyed by the wave.

Solution:

The average power per unit area is equal to the average Poynting vector, which from (3) has a magnitude.

$$S_{av} = \frac{1}{2} \hat{z} \frac{E_1^2 + E_2^2}{Z_0} = \frac{1}{2} \hat{z} \frac{E^2}{Z_0}$$

$$S_{av} = \frac{1}{2} \frac{3^2 + 6^2}{377} = \frac{1}{2} \frac{45}{377} \approx 60mW m^{-2}$$

Antenna Arrays

The pattern of any antenna can be regarded as produced by an array of point sources.

Consider a linear array of n standard isotropic antenna having equal amplitude of current and equally spaced. We may consider the field strength at a distant point, in the direction inclined ϕ to the linear antenna placement.

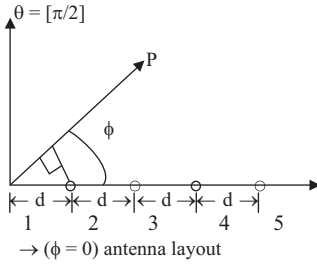


Fig. 5.15

Parameters: Amplitude Unity

ψ = total phase difference between adjacent radiators.

d = spacing between adjacent radiators

δ = phase difference in feed from source between adjacent radiators.

λ = wavelength

$\delta r = \frac{2\pi}{\lambda} d$, phase differences between adjacent radiators due to spacing.

Total phase different in direction ϕ .

$$\psi = \left(\frac{2\pi d}{\lambda} \cos \phi \right) + \delta = \delta r \cos \phi + \delta$$

Assume amplitude of fields from the source are all equal and equal to unity.

Classification of Antenna Arrays

Broad Side Array

(a) All radiators are fed in same phase
 $\delta = 0$

(b) Phase is due to spacing between radiators only.

$$\psi = \frac{2\pi d}{\lambda} \cos \phi = \delta r \cos \phi$$

(c) Field strength is maximum when

$$\phi = (2K+1) \frac{\pi}{2} \text{ or } \psi = 0, \text{ i.e., all radiators are in phase}$$

where, $K = 0, 1, 2, \dots$ i.e., $\phi = 90^\circ, 60^\circ, 120^\circ$

(d) Field is minimum when $\phi = 90$ i.e., $\frac{\pi}{2}$ and $\frac{3\pi}{2}$

(e) There are secondary maximum, which can be determined only by analysis of specific arrays. Because the primary maximum lobe of radiation occurs normal to the alignment of radiators, such array is called Broadside array.

$$\psi = \frac{2\pi d}{\lambda} \cos \phi = \frac{2\pi d}{\lambda} \sin \theta$$

$$\sin \frac{n\psi}{2} = \sin \frac{n}{2} \frac{2\pi d}{\lambda} \sin \theta$$

$$\sin \frac{n\psi}{2} = \sin \frac{\pi nd}{\lambda} \sin \theta$$

For this to be zero,

$$\frac{\pi nd}{\lambda} \sin \theta = K\pi, K=1, 2, 3, \dots$$

$$\sin \theta = \frac{K\lambda}{nd}$$

$$\theta = \sin^{-1} \frac{K\lambda}{nd}$$

For first null direction, $K = 1$,

$$\theta = \sin^{-1} [\lambda/nd]$$

Beam lobe width $= 2\theta = 2 \sin^{-1} [\lambda/nd]$

Beam lobe width as function of number of radiators.

Consider a specific case when $d = [\lambda/2]$

and $n = 4$

$$2\theta = 2 \sin^{-1} \frac{\lambda/2}{4 \cdot \lambda}$$

Beam width $= 2 \sin^{-1} (0.5) = 60^\circ$

If instead $n = 10$,

$$2\theta = 2 \sin^{-1} \frac{\lambda/2}{10\lambda} = \sin^{-1} (0.2) = 23^\circ$$

Beam width reduces with the number of radiators or the directional pattern becomes sharper and more intense in the vertical direction, when the number of radiators increases.

End Fire Array

A radiator array in which the maximum field direction is in the direction of the radiators is called End fire array.

The requirement is $\phi = 0$

$$\psi = \frac{2\pi d}{\lambda} \cos \phi + \delta = \frac{2\pi d}{\lambda} + \delta$$

(a) For maximum field strength, all radiators should be in phase of $\psi = 0$

$$\text{when } \frac{2\pi d}{\lambda} + \delta = 0$$

$$\frac{2\pi d}{\lambda} = -\delta$$

$$\frac{2\pi d}{\lambda} = -\delta \text{ is the phase arising from spacing between the radiators. This leads to the requirement that}$$

(b) Phase of feeding the radiators should be retarded progressively by the same amount as the spacing between the radiators.

(c) Maximum field strength is in the direction of the radiators.

(d) Minimum field is normal to the direction of the radiators.

(e) Secondary maximum occurs in the same way as for broad side antenna.

QUESTION BANK

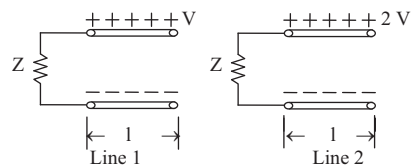
LEVEL 1

1. Phase velocity ' v_p ' and the group velocity ' v_g ' in a wave guide (' c ' is velocity of light) are related as
 - (a) $v_p v_g = c^2$
 - (b) $v_p + v_g = c$
 - (c) $v_p/v_g = \text{a constant}$
 - (d) $v_p + v_g = \text{a constant}$
2. The equation $\nabla \cdot J = 0$ is known as
 - (a) Poisson's equation
 - (c) Laplace equation
 - (b) Continuity equation
 - (d) Maxwell equation
3. A transmission line has primary constants R , L , G and C , and secondary constants Z_0 and $\gamma (= \alpha + j\beta)$. If the line is loss less, then
 - (a) $R = 0$, $G \neq 0$ and $\alpha = 0$
 - (b) $R = 0$, $G = \alpha$, 0 and $\beta = |\gamma|$
 - (c) $G = 0$ and $\alpha = \beta$
 - (d) $R = 0$, $G = 0$, $\alpha = 0$ and $\beta = |\gamma|$
4. In a uniform plane wave, the value of $(|E|/|H|)$ is
 - (a) $\sqrt{\mu/\epsilon}$
 - (b) $\sqrt{\epsilon/\mu}$
 - (c) 1
 - (d) $\sqrt{\mu\epsilon}$
5. Which one of the following is not a correct Maxwell equation?
 - (a) $\nabla \times \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{J}$
 - (b) $\nabla \times \vec{E} = \frac{\partial \vec{H}}{\partial t}$
 - (c) $\vec{\nabla} \cdot \vec{D} = \rho$
 - (d) $\vec{\nabla} \cdot \vec{B} = 0$
6. Gauss law relates the electric field intensity E with the volume charge density ρ at a point as
 - (a) $\nabla \times E = \epsilon_0 \rho$
 - (b) $\nabla \times E = \epsilon_0 \rho$
 - (c) $\nabla \times E = [\rho/\epsilon_0]$
 - (d) $\nabla \cdot E = [\rho/\epsilon_0]$
7. The input impedance of a $\lambda/8$ long short-circuit section of a loss less transmission line is
 - (a) Zero
 - (b) Inductive
 - (c) Capacitive
 - (d) Infinite
8. A boundary separates two magnetic materials of permeability μ_1 and μ_2 . The magnetic field vector in μ_1 is H_1 with a normal component H_{n1} and tangential component H_{t1} while that in μ_2 is H_2 with a normal component H_{n2} and a tangential component H_{t2} . Then the derived conditions would be
 - (a) $H_1 = H_2$ and $H_{t1} = H_{t2}$
 - (b) $H_{t1} = H_{t2}$ and $\mu_1 H_{n1} = \mu_2 H_{n2}$
 - (c) $H_1 = H_2$ and $\mu_1 H_{n1} = \mu_2 H_{n2}$
 - (d) $H_1 = H_2$, $H_{t1} = H_{t2}$ and $\mu_1 H_{n1} = \mu_2 H_{n2}$
9. The input impedance of a short circuited quarter wave long transmission line is
 - (a) purely reactive
 - (b) purely resistive
 - (c) dependent on the characteristic impedance of the line
 - (d) rational
10. Laplacian of a scalar function V is
 - (a) Gradient of V
 - (b) Divergence of V
 - (c) Gradient of the gradient of V
 - (d) Divergence of the gradient of V
11. An infinitely long line charge of uniform charge density ρ_0 C/m is situated parallel to and at a distance from the grounded infinite plane conductor. This field problem can be solved by which one of the following?
 - (a) By conformal transformation
 - (b) By method of images
 - (c) By Laplace's equation
 - (d) By Poisson's equation
12. Which one of the following statements is correct? A right circularly polarized wave is incident from air onto a polystyrene ($\epsilon_r = 2.7$). The reflected wave is
 - (a) Right circularly polarized
 - (b) Left circularly polarized
 - (c) Right elliptically polarized
 - (d) Left elliptically polarized
13. What is the effect of the earth's magnetic field in the reflected wave at frequencies in the vicinity of gyro frequency?
 - (a) attenuation in the reflected wave
 - (b) Decreased attenuation in the reflected wave
 - (c) Increased attenuation in the reflected wave
 - (d) Nominal attenuation in the reflected wave
14. Which one of the following statements is correct? Short-circuited stubs are preferred to open circuited stub because the latter are
 - (a) More difficult to make and connect
 - (b) Made of transmission line with a different characteristic impedance
 - (c) Liable to radiate energy
 - (d) Incapable of giving a full range of frequencies
15. Which one of the following concepts is used to find the expression of radiated $\vec{E}$ and $\vec{H}$ field due to a magnetic current element?
 - (a) Concept of vector magnetic potential
 - (b) Concept of scalar electric potential
 - (c) Concept of scalar magnetic potential
 - (d) Concept of vector electrical potential
16. For an electromagnetic wave incident on a conducting medium, the depth of penetration
 - (a) is directly proportional to the attenuation constant
 - (b) is inversely proportional to the attenuation constant
 - (c) has a logarithmic relationship with the attenuation constant
 - (d) is independent of the attenuation constant

17. To couple a coaxial line to a parallel wire, it is best to use a
 - (a) Balun
 - (b) Slotted line
 - (c) Directional coupler
 - (d) Quarter wave transformer
18. A quarter wave transformer can be used for matching accurately
 - (a) Inductive loads only
 - (b) Capacitive loads only
 - (c) Loads with any nature of reactance
 - (d) Purely resistive loads only
19. Equipotential surfaces about a point charge are in which one of the following forms?
 - (a) Spheres
 - (b) Planes
 - (c) Cylinders
 - (d) Cubes
20. What does the expression $(1/2)\vec{J} \cdot \vec{A}$ represent?
 - (a) Electric energy density
 - (b) Magnetic energy density
 - (c) Power density
 - (d) Radiation resistance
21. Which one of the following is the correct statement? A rectangular coaxial line can support
 - (a) Only TEM mode of propagation
 - (b) Both TEM and TE modes of propagation
 - (c) Either TE or TM mode of propagation
 - (d) TEM, TE or TM mode of propagation
22. Which one of the following modes has the highest cut-off wavelength in a rectangular waveguide?
 - (a) TE_{10}
 - (b) TE_{01}
 - (c) TM_{01}
 - (d) TM_{11}
23. Which one of the following is the characteristic impedance of lossless transmission line?
 - (a) $\sqrt{R/G}$
 - (b) $\sqrt{L/G}$
 - (c) $\sqrt{L/C}$
 - (d) $\sqrt{R/C}$
24. A quarter wave impedance transformer is terminated by a short circuit. What would its input impedance be equal to?
 - (a) The line characteristic impedance
 - (b) Zero
 - (c) Infinity
 - (d) Square root of the line characteristic impedance
25. Scattering parameters are more suited than impedance parameters to describe a waveguide junction because
 - (a) the scattering parameters are frequency invariant whereas the impedance parameters are not so
 - (b) scattering matrix is always unitary
 - (c) impedance parameters vary over unacceptable wide ranges
 - (d) scattering parameters are directly measurable but impedance parameters are not so
26. A copper metal ring is spinning at a constant very high speed around an axis passing through center of the ring and perpendicular to its plane. The ring is suddenly stopped. Which of the following statements is the most correct?
 - (a) On stopping the ring, there would be a definite amount of charge to flow in the ring and hence an electric current would be produced.
 - (b) Since the copper metal is electrically neutral, there would not be any net flow of charges and hence no current.
 - (c) Since the free electrons tend to keep moving due to spinning of the ring, there must exist a simple relation between the electron's motion and electric field which would causes a definite amount of charge to flow and hence current is produced.
 - (d) This is never possible that a current is produced, as there is no external magnetic field which would charge the magnetic flux across the spinning ring, as per Faraday's law of electromagnetic induction.
27. Maxwell's equations establish the relationship between $\vec{E}$, $\vec{D}$, $\vec{H}$ and $\vec{B}$ at any point in a continuous medium. When we move from one medium to another, then which of the following statement/statements is/are correct?
 - (a) At the boundary separating the two media, the tangential components of $\vec{E}$ and $\vec{H}$ are continuous.
 - (b) At the boundary separating the two media, the tangential components of only $\vec{E}$ are continuous.
 - (c) If there are surface charges present on the boundary, then normal component of $\vec{D}$ is continuous.
 - (d) If there are no surface charges, then normal component of $\vec{D}$ is discontinuous.
28. Which of the following equations satisfies Maxwell's equations?
 - (a) $E_x = E_y = 0$; $E_z = \cos(y - ct)$
 $B_x = \cos(y - ct)$; $B_y = B_z = 0$
 - (b) $E_x = E_y = 0$; $E_z = \cos(y - ct)$
 $B_y = \cos(y - ct)$; $B_x = B_z = 0$
 - (c) $E_y = \cos(y - ct)$; $E_x = E_z = 0$
 $B_x = \cos(y - cy)$; $B_y = B_z = 0$
 - (d) none of the above
29. Consider a parallel plate capacitor being charged. Identify the incorrect statements.
 - (a) Energy stored in the capacitor does not enter it through the connecting wires but through the space around the wires and plates of capacitor.
 - (b) Rate at which energy flows into this volume is equal to the integration of the Pointing vector over the boundary of the volume the plates.
 - (c) The Pointing vector points everywhere radially outward of the volume between the plates.
 - (d) The Pointing vector points everywhere, radially into the volume between the plates.
30. In a transmission line terminated with a load equal to the characteristics impedance, the reflection coefficient is
 - (a) zero
 - (b) + 1
 - (c) - 1
 - (d) infinity
31. A transmission line has a VSWR of 2, reflection coefficient is
 - (a) 1/3
 - (b) 0
 - (c) 1/4
 - (d) 1/2

32. A quarter wave transformer is used for matching the transmission line to the load Z_L when Z_L is
 (a) high (b) low
 (c) purely resistive (d) complex
33. $\lambda/4$ a transformer is used for
 (a) Light loads
 (b) High frequency load
 (c) Connecting high impedance loads to low impedance loads
 (d) Reducing distortion in transmission lines
34. Joule/Coulomb is the unit of
 (a) Electric field potential (b) Potential
 (c) Charge (d) None of the above
35. Maxwell's divergence equation for the magnetic field is given by
 (a) $\nabla \times \vec{B} = 0$ (b) $\nabla \cdot \vec{B} = 0$
 (c) $\nabla \times \vec{B} = \vec{P}$ (d) $\nabla \cdot \vec{B} = \vec{P}$
36. The electric field lines and equipotential lines
 (a) Are parallel to each other
 (b) Are one and the same
 (c) Cut each other orthogonally
 (d) Can be inclined to each other at any angle
37. Two electrons moving parallel to each other with the same velocity will
 (a) Attract each other if they move in the same direction.
 (b) Repel each other more strongly when moving in same direction than when moving in opposite directions.
 (c) Repel each other less strongly when moving in same direction than when moving in opposite direction.
 (d) Repel each other with the same force when moving in the same or opposite direction.
38. Distortion in the transmission of carrier frequencies in an underground cable can be eliminated by using
 (a) Inductive loading (b) Resistive loading
 (c) Capacitive loading (d) Shielding
39. The type of time variation ($\partial/\partial t$) implied with reference to the field quantities in Maxwell's equation is
 (a) Sinusoidal
 (b) Non-sinusoidal
 (c) Both sinusoidal and non-sinusoidal
 (d) Exponential
40. The equation $\nabla \times \vec{E} = \partial \vec{B}/\partial t$ is the generalization of
 (a) Ampere's law (b) Gauss's law
 (c) Faraday's law (d) Biot-Savart's law
41. The skin depth (δ) due to RF current is equal to (ω = angular frequency, μ = permeability and σ = conductivity)
 (a) $[2/\omega \mu \sigma]$ (b) $[2/\sqrt{\omega \mu \sigma}]$
 (c) $[2/\omega \mu \sigma]^{1/2}$ (d) $[\sqrt{2/\omega \mu \sigma}]$
42. The value of series inductance (L) in Henries per km for minimum attenuation in the loading of the transmission line is given by (G = shunt capacitance per km and R = series resistance per km)
 (a) $L = [CR/G]$ (b) $L = [G/CR]$
 (c) $L = [\sqrt{CR/G}]$ (d) $L = [\sqrt{1/GCR}]$
43. To couple a coaxial line to a parallel wire line, it is best to use a
 (a) slotted line (b) balun
 (c) directional coupler (d) $\lambda/4$ transformer
44. Two identical coaxial circular loops carry the same current circulating in the same direction. If the loops approached each other, then the current in
 (a) Each one of them will increase
 (b) Both of them will remain the same
 (c) Each one of them will decrease
 (d) One will increase while in the other, the current will decrease
45. Kirchhof's current law for direct currents is implicit in the expression
 (a) $\nabla \cdot \vec{D} = \rho$ (b) $\int \vec{j} \cdot \vec{n} ds = 0$
 (c) $\nabla \cdot \vec{B} = 0$ (d) $\nabla \cdot \vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t}$
46. A rectangular loop in the $x-z$ plane bounded by the lines $x=0$, $x=a$, $z=0$ and $z=b$, is in a time-varying magnetic field given by

$$\vec{B} = B_0 \cos \omega t \vec{a}_y$$
 where, B_0 = Constant
 ω = angular frequency
 $\vec{a}_y$ = unit vecttor in the y direction.
 The emf induced in the loop is given by
 (a) $abB_0 \cos \omega t$ (b) $abB_0 \omega \sin \omega t$
 (c) $B_0 \omega \sin \omega t$ (d) zero
47. In a broadside array, the maximum radiation
 (a) Occurs at 90° to the line of the array
 (b) Occurs at 45° to the line of the array
 (c) Occurs along the line of the array
 (d) Could occur at any angle to the line of the array
48. At a certain frequency f , a uniform plane is found to have established a wavelength λ in a *good conductor*. If the source frequency is doubled, then the wavelength would change to
 (a) $\frac{\lambda}{\sqrt{2}}$ (b) $\sqrt{2} \lambda$
 (c) 2λ (d) 4λ
49. Two lossless transmission lines 1 and 2 shown in the given figure have each a characteristic impedance Z . Line 1 is charged to a voltage of V and line 2 to a voltage of $2V$. Then both of them are discharged through resistances Z as shown, if line 1 gets fully discharged in time T , then line 2 will get fully discharged in time



- (a) $\frac{T}{4}$ (b) $\frac{T}{2}$
 (c) T (d) $2T$

50. For a current element Idl situated at an arbitrary point, the magnetic vector potential A equals (R is the distance of the observation point from the centre of the current element)
- $\mu Idl(4\pi R)$
 - $\mu Idl(4\pi R^2)$
 - $\mu Idl/(4\pi R)$
 - $\mu Idl/(2\pi R)$
51. Tangential component of the electric field on a perfect conductor will be
- Infinite
 - Zero
 - Same as the normal field component and 90° out of phase
 - Same as the normal component but 180° out of phase
52. The directivity of an isotropic antenna is
- zero
 - less than unity
 - unity
 - infinity
53. For the volume charge density ρ_v , the divergence of the electric field intensity will be equal to
- $\frac{\rho_v}{\epsilon_o}$
 - $\epsilon_o^2 \rho_v$
 - $\epsilon_o \rho_v$
 - $\frac{\rho_v}{\epsilon_o^2}$
54. If the static magnetic flux density is $\vec{B}$, then
- $\nabla \times \vec{B} = 0$
 - $\nabla \cdot \vec{B} = 0$
 - $\nabla \cdot \vec{B} = \vec{J}$
 - $\nabla \times \vec{B} = \vec{J}$
55. Cavity resonators are used in
- MF band
 - F band
 - VHF band
 - SHF band
56. The operator 'del' (∇) is a
- Vector space function
 - Vector time function
 - Scalar space function
 - Scalar time function
57. The unit of the pointing vector is
- Power
 - Power density
 - Energy
 - Energy density
58. The units of J_s and J the surface and volume current densities are respectively
- $A/m^2, A/m^3$
 - $A/m, A/m^2$
 - $A/m, A/m^3$
 - $A, A/m$
59. If the vector field $\vec{A} = x\vec{a}_x + y\vec{a}_y + Kz\vec{a}_z$ represents a magnetic field, then the value of K must be
- 1
 - 2
 - 1
 - 2
60. When the load impedance is equal to the characteristic impedance of the transmission lines, then the reflection coefficient and standing wave are respectively
- 0 and 0
 - 1 and 0
 - 0 and 1
 - 1 and 1
61. If the vector field $\vec{A}$ and $\vec{B}$ are conservative, then
- $\vec{A} \times \vec{B}$ is solenoidal
 - $\vec{A} \times \vec{B}$ is conservative
 - $\vec{A} + \vec{B}$ is solenoidal
 - $\vec{A} - \vec{B}$ is solenoidal
62. The value of $\oint_C \vec{A} \cdot d\vec{l}$ along a circle of radius 2 units is
- zero
 - 2π
 - 4π
 - 8π
63. The field at any point on the axis of a current carrying circular coil will be
- Perpendicular to the axis
 - Parallel to the axis
 - At an angle of 45° with the axis
 - Zero
64. A straight conductor of circular cross-section carries a current. Which one of the following statements is true in this regard?
- No force acts on the conductor at any point.
 - An axial force acts on the conductor tending to increase its length.
 - A radial force acts towards the axis tending to reduce its cross-section.
 - A radial force acts away from the axis tending to increase its cross-section.
65. In a multilayer dielectric material, on the either side of boundary
- The normal component of electrical displacement is same.
 - The normal component of electrical field is same.
 - The tangential component of electrical displacement is necessarily zero.
 - The tangential component of electrical field necessarily zero.
66. The relation between electric polarization and susceptibility indicates that electric polarization is
- Independent of susceptibility
 - Inversely proportional to susceptibility
 - Proportional to square root of susceptibility
 - Proportional to susceptibility
67. If the frequency of a plane electromagnetic wave increases four times, the depth of penetration, when the wave is incident normally on a good conductor will
- Increase by factor of two
 - Decrease by a factor of four
 - Remain same
 - Decrease by a factor of two
68. Across the surface of a charged conductor, the electric
- Field is continuous
 - Potential is discontinuous
 - Field is discontinuous
 - None of the above
69. Two electrons moving parallel to each other, with the same velocity, will
- Attract each other if they move in the same direction
 - Repel each other more strongly when moving in same direction than when moving in opposite direction
 - Repel each other less strongly when moving in same direction than when moving in opposite direction
 - Repel each other with the same force when moving in the same or opposite direction

70. There is a constant homogeneous magnetic field pointing in vertical direction. A metallic wire in the form of a square is rotated about a horizontal axis passing through the middle points of its opposite arms. The e.m.f. generated in the square is
 (a) Zero (b) Finite and constant
 (c) Oscillating (d) Varying with time t
71. The electric potential due to an electric dipole of length L at a point distance r away from it will be doubled if the
 (a) length L of the dipole is doubled
 (b) r is doubled
 (c) r is halved
 (d) L is halved
72. Joule/Coulomb is the unit of
 (a) Electric field potential (b) potential
 (c) Charge (d) none of the above
73. Maxwell's divergence equation for the magnetic field is given by
 (a) $\nabla \times B = 0$ (b) $\nabla \times B = 0$
 (c) $\nabla \times B = \mu_0 j$ (d) $\nabla \times B = \mu_0 j$
74. The electric field lines and equipotential lines
 (a) Are parallel to each other
 (b) Are one and the same
 (c) Cut each other orthogonally
 (d) Can be inclined to each other at any angle
75. Which law is synonymous to the occurrence of diamagnetism?
 (a) Ampere's law (b) Maxwell's law
 (c) Coulomb's law (d) Lenz's law
76. Consider the following statements:
 The characteristic impedance of a transmission line can increase with the increase in
 1. resistance per unit length
 2. conductance per unit length
 3. capacitance per unit length
 4. inductance per unit length
 Which of these statements are correct?
 (a) 1 and 2 (b) 2 and 3
 (c) 1 and 4 (d) 3 and 4
77. A medium behaves like dielectric when the
 (a) Displacement current is just equal to the conduction current
 (b) Displacement current is less than the conduction current
 (c) displacement current is much greater than the conduction current
 (d) Displacement current is almost negligible
78. What will be the reflected wave for an elliptically polarized wave incident on the interface of a dielectric at the Brewster angle?
 (a) Elliptically polarized
 (b) Linearly polarized
 (c) Right circularly polarized
 (d) Left circularly polarized
79. Which one of the following statements is correct?
 The wavelength of a wave propagating in a wave guide is
 (a) Smaller than the free space wavelength
 (b) Greater than the free space wavelength
 (c) Directly proportional to the group velocity
 (d) Inversely proportional to the phase velocity
80. Which one of the following statements is correct?
 A wave guide can be considered to be analogous to a
 (a) Low pass filter (b) High pass filter
 (c) band pass filter (d) Band stop filter
81. Which one of the following statements is correct?
 If the Fermi level lies midway between the conduction and valence bands, then the semiconductor is
 (a) Intrinsic (b) Extrinsic
 (c) P-type (d) N-type
82. Which one of the following statements is correct?
 Superconductors are popularly used for
 (a) Generating very strong magnetic field
 (b) Reducing $i^2 R$ losses
 (c) Generating electrostatic field
 (d) Generating regions free from magnetic field
83. Impedance inversion may be obtained with
 (a) A short-circuited stub (b) An open-circuited stub
 (c) A quarter-wave line (d) A half-wave line
84. Which one of the following statements does not state that electrostatic field is conservative?
 (a) The curl of $\vec{E}$ is identically zero
 (b) The potential difference between two points is zero
 (c) The electrostatic field is a gradient of a scalar potential
 (d) The work done in a closed path inside the field is zero
85. Where is the Laplace's equation valid?
 (a) Only in free space
 (b) Only in conductors
 (c) Only in charge free dielectric regions
 (d) Only in cavities bounded on all sides by conducting walls
86. Equipotential surfaces about a pair of equal and opposite linear charges exist in what form?
 (a) Concentric spheres
 (b) Concentric cylinders
 (c) Non-concentric cylinders
 (d) Planes
87. Consider the following statements regarding EM wave.
 1. An EM wave incident on a perfect dielectric is partially transmitted and partially reflected.
 2. An EM wave incident on a perfect conductor is fully reflected.
 3. When an EM wave is incident from a more dense medium to less dense medium at an angle equal to or exceeding the critical angle. The wave suffers total internal reflection.
 Which of the statements given above are correct?
 (a) Only 1 and 2 (b) Only 2 and 3
 (c) Only 1 and 3 (d) 1, 2 and 3

88. The input impedance of short-circuited lossless line of length less than a quarter wavelength is
 (a) purely resistive (b) purely inductive
 (c) purely capacitive (d) complex
89. With solid dielectrics such as those used in twisted pair and coaxial cables, the shunt conductance will be proportional to
 (a) The frequency and dielectric constant but independent of the power factor
 (b) The frequency and power factor but independent of the dielectric constant
 (c) The power factor and dielectric constant but independent of the frequency
 (d) The frequency, dielectric constant and power factor
90. For transmission line load matching over a range of frequencies, it is best to use a
 (a) Balun
 (b) Double stub
 (c) Broad band directional coupler
 (d) Single stub of adjustable position
91. In an ideal transmission line with matched load, the voltage standing wave ratio and reflection coefficient are respectively
 (a) 1 and 1 (b) Infinity and one
 (c) Infinity and zero (d) One and zero
92. Which one of the following sets of equations is independent in Maxwell's equations?
 (a) The two curl equations
 (b) The two divergence equations
 (c) Both the curl and divergence equations
 (d) The two curl equations combined with the continuity equation
93. The depth of penetration or skin depth for an electromagnetic field of frequency 'f' in a conductor of resistivity ρ and permeability μ is
 (a) Inversely proportional to ρ and f and directly proportional to μ
 (b) Directly proportional to ρ and inversely proportional to f and μ
 (c) Directly proportional to f and inversely proportional to ρ and μ
 (d) Inversely proportional to ρ and μ and directly proportional to f
94. Solutions of Laplace's equation, which are continuous through the second derivative, are called
 (a) Bessel functions (b) Odd functions
 (c) Harmonic functions (d) Fundamental functions
95. For an elliptically polarized wave incident on the interface of a dielectric at the Brewster angle, the reflected wave will be
 (a) Elliptically polarized
 (b) Linearly polarized
 (c) Right circularly polarized
 (d) Left circularly polarized
96. Which of the following statement regarding electric flux is true?
 1. Electric flux begins on positive charges and terminates on negative charges
 2. Flux is in same direction as the electric field $\vec{E}$
 3. Flux density is proportional to the magnitude of $\vec{E}$
 4. In the SI system of units, total flux emanating from a charge of $Q(C)$ is $Q(C)$. A single line will emanate from 1 C of charge
 (a) 1 only (b) 1 and 2 only
 (c) 1, 2, and 3 only (d) 1, 2, 3, and 4
97. The electric potential due to an electric dipole of length L at a point distance r away from it will be doubled if the
 (a) Length L of the dipole is doubled
 (b) r is doubled
 (c) r is halved
 (d) r is halved
98. Fields are said to be circularized if their magnitudes are
 (a) Equal and they are in phase
 (b) Equal but they differ in phase by $\pm 90^\circ$
 (c) Unequal and they differ in phase by $\pm 90^\circ$
 (d) Unequal and they differ in phase by
99. Consider the following statements regarding a linearly polarized wave travelling in a dielectric medium which is incident at the planar interface. The transmitted wave in the second medium will be
 (1) growing (2) non-uniform
 (3) attenuated (4) linearly polarized
 (5) circularly polarized (6) elliptically polarized
 Of these statements:
 (a) 2, 4 and 6 are correct (b) 1, 2 and 4 are correct
 (c) 3, 4 and 5 are correct (d) 2, 4 and 5 are correct
100. P is a point at a large distance from the center O of a short dipole formed by two point charges all lying on a horizontal plane. If θ is the angle between OP and the dipole axis, then θ component of the E-field at P is
 (a) given by $\sin \theta$ (b) given by $\cos \theta$
 (c) given by $\tan \theta$ (d) independent of θ

LEVEL 2

1. A magnetic field $\vec{B} = (\vec{a}_x + 2\vec{a}_y - 4\vec{a}_z)$ exists at a point. If a test charge moving with a velocity $\vec{V} = \vec{V}_o(3\vec{a}_x - \vec{a}_y + 2\vec{a}_z)$ experience no force at a certain point, the electric field at that point will be
 (a) $\vec{E} = -V_o(3\vec{a}_x - 2\vec{a}_y - 4\vec{a}_z)$
 (b) $\vec{E} = -V_o(14\vec{a}_y + 7\vec{a}_z)$
 (c) $\vec{E} = -\frac{V_o}{\mu}(14\vec{a}_y + 7\vec{a}_z)$
 (d) $\vec{E} = +\frac{V_o}{\mu}(14\vec{a}_y + 7\vec{a}_z)$

2. The ratio of velocity of propagation of EM waves in overhead transmission line and in a cable with a dielectric of permittivity 4, is
 (a) 0.25 (b) 0.5
 (c) 2.0 (d) 4.0
3. The relation between the wave impedance (Z_w) and the intrinsic impedance (Z_i) for a TEM wave is given by
 (a) $Z_w = 0.5 Z_i$ (b) $Z_w = 1/Z_i$
 (c) $Z_w = 2 Z_i$ (d) $Z_w = Z_i$
4. An air-filled rectangular waveguide has inside dimensions 7×3.5 cm. The ratio of cut-off frequency in TE_{01} mode to that in TE_{10} mode is
 (a) 0.5 (b) 0.707
 (c) 1.0 (d) 2.0
5. Two vectors $\vec{A}$ and $\vec{B}$ are such that $\vec{A} + \vec{B} = n\vec{A}$ where n is a positive scalar < 1 . The angle between $\vec{A}$ and $\vec{B}$ is
 (a) $\pi/2$ (b) $3\pi/4$
 (c) π (d) 2π
6. The electric field across a dielectric-air interface is shown in the given figure. The charge density on the interface is

$$\epsilon_r = 1 \uparrow \vec{E} = \vec{a}_x$$

$$\epsilon_r = 2 \uparrow \vec{E} = 2\vec{a}_x$$

 (a) $-4\epsilon_0 C/m^2$ (b) $-3\epsilon_0 C/m^2$
 (c) $-2\epsilon_0 C/m^2$ (d) $-\epsilon_0 C/m^2$
7. A lossless transmission line is terminated in a load of reflection coefficient $\Gamma = 0.5 / \angle \pi/3$. The distance of the first minimum from the load end in terms of the wavelength is
 (a) $\lambda/3$ (b) $\lambda/4$
 (c) $2\lambda/3$ (d) $3\lambda/4$
8. A flat slab of dielectric ($\epsilon_r = 5$) is placed normal to a uniform field with a flux density $D = 1$ coulomb/m². The slab is uniformly polarized. Polarization ' P ' in the slab (in Coulomb/m²) will be
 (a) 0.8 (b) 1.2
 (c) 4.0 (d) 6.0
9. A circular loop has its radius increasing at a rate of 2 m/s. The loop is placed perpendicular to a constant magnetic field of 0.1 Wb/m². When the radius of the loop is 2m, the emf induced in the loop will be
 (a) $0.8 \pi V$ (b) $0.4 \pi V$
 (c) $0.2 \pi V$ (d) zero
10. Two conducting shell of radii r_1 and r_2 ($r_1 > r_2$) each with a charge ' Q ' are placed far apart in uniform external electric field. The space surrounding each shell is filled with the same dielectric material. In this situation, the
 (a) Shells will not experience any force
 (b) Shell will experience identical forces
 (c) Shell with radius r_1 will experience a greater force
 (d) Shell with radius r_2 will experience a greater force
11. If the electric field component of a wave is $E = \cos(6 \times 10_8 \pi t + 50z) a_x$ V/m. then the wave
 (a) Propagates in x -direction
 (b) Amplitude is $\sqrt{2}$ V/m
 (c) Is not traveling in free space
 (d) Propagates in $+z$ direction
12. The velocity of the plane wave $\sin^2(\omega t - \beta x)$ is
 (a) $\frac{2\omega}{\beta}$ (b) $\frac{\omega}{2\beta}$
 (c) $\frac{\omega^2}{\beta^2}$ (d) $\frac{\omega}{\beta}$
13. The incident wave on a lossless line carries an average power of 1.0 W. The load end reflection coefficient is 1/3. The average power absorbed by the load is
 (a) 1/3 W (b) 2/3 W
 (c) 4/9 W (d) 8/9 W
14. The magnetic field intensity (in amperes/metre) at the centre of a circular coil of diameter 1 metre and carrying a current of 2 amperes is
 (a) 8 (b) 4
 (c) 3 (d) 2
15. A uniform plane wave travelling in a perfect dielectric is incident normally on the surface of perfect conductor. Then
 (a) The wave is transmitted into the conductor without attenuation
 (b) 50% of the incident wave is transmitted and 50% is reflected
 (c) A standing wave is set up in the conducting medium
 (d) A standing wave is set up in the dielectric
16. A 24 V battery of internal resistance $r = 4$ ohm connected to a variable resistance R . the rate of heat dissipated in the resistor is maximum when the current drawn from the battery is I . The current drawn from the battery will be $I/2$ when R is equal to
 (a) 8 ohm (b) 12 ohm
 (c) 16 ohm (d) 20 ohm
17. A conductor in $(x - y)$ plane having length 1 m is moving with a velocity $= (2i + 3j + k)$ m/sec. A magnetic induction field $B = (i + 2j)$ Wb/m² is applied to the conductor. The potential difference between the ends of the conductor is
 (a) Zero (b) 4.88 volt
 (c) $\sqrt{6}$ volt (d) none of these
18. Two parallel plates, having separation x ($x <<$ lateral dimensions of the plates) are connected by a wire. A point charge q is located between the plates at a distance x_1 from one plate ($x_1 < x$). The magnitude of the total surface charge on the inner surface of each plate is
 (a) Zero, because two plates are connected
 (b) $+q/2$
 (c) $+q$
 (d) $-q$
19. A conductor having surface density is embedded in a dielectric medium of permittivity. The electric field in the medium is E . If

it is known that the pressure p on the conductor surface is equal to the electric energy density in the medium, then p (in SI unit) is given by

- (a) $\sigma^2/2$ (b) $\sigma/2\epsilon$
(c) $\sigma/4\pi\epsilon$ (d) $\sigma^2/2\epsilon$
20. A generator of 50 ohm internal impedance and operating at 1 GHz feeds a 75 Ω load via a coaxial line of characteristic impedance 50 ohm. The voltage Standing Wave Ratio on the feed line is
(a) 0.5 (b) 1.5
(c) 2.5 (d) 1.75
21. By inserting a plate of a dielectric between the plates of a parallel plates capacitor, the energy stored in the capacitor is increased five times. The dielectric of the material is
(a) 1/25 (b) 1/5
(c) 5 (d) 25
22. The dimension of flux density is
(a) $MT^{-1}Q^{-1}$ (b) $MT^{-2}Q^{-2}$
(c) MT^1Q^1 (d) $MT^{-1}Q^{-2}$
23. If $\vec{H} = 0.1 \sin(108\pi t + \beta y) \hat{a}_z$ A/m for plane wave propagating in free space, then the time average Poynting vector is
(a) $0.6 \pi \sin^2 \beta y \hat{a}_y$ W/m² (b) $-0.6 \pi \hat{a}_y$ W/m²
(c) $1.2 \pi \hat{a}_y$ W/m² (d) $-1.2 \pi \hat{a}_y$ W/m²
24. In a hundred-turn coil, if the flux through each turn is $(t^2 - 2t)$ m Wb, the magnitude of the induced emf in the coil at a time of 4s is
(a) 46 mV (b) 56 mV
(c) 4.6 V (d) 5.6 V
25. If the velocity of electromagnetic wave in free space is 3×10^8 m/s, the velocity in a medium with ϵ_r of 4.5 and μ_r of 2 would be
(a) 1×10^8 m/s (b) 3×10^8 m/s
(c) 9×10^8 m/s (d) 27×10^8 m/s
26. A transmission line having 50 Ω impedance is terminated in a load of $(40 + j30)\Omega$. The VSWR is
(a) $j 0.033$ (b) $0.8 + j 0.6$
(c) 1 (d) 2
27. Polystyrenes has a relative permittivity of 2.7. If the wave is incident at an angle ' θ_i ' of 30° from air onto polystyrene, the angle of transmission will be nearly
(a) 0.2° (b) 2°
(c) 18° (d) 48°
28. A solid cylindrical conductor of radius ' R ' has a uniform current density. The magnetic field ' H ' inside the conductor at a distance ' r ' from the axis of the conductor is
(a) $I/2\pi r$ (b) $I/4\pi r$
(c) $Ir/2\pi R^2$ (d) $Ir/4\pi R^2$
29. A coil of resistance of 5 Ω and inductance 0.4 H is connected to a 50V d.c supply. The energy stored in the field is
(a) 10 joules (b) 20 joules
(c) 40 joules (d) 80 joules
30. A 3 μ F capacitor is charged by a constant current of 2 μ A for six seconds. The voltage across the capacitor at the end of charging will be
(a) 3 V (b) 4 V
(c) 6 V (d) 9 V
31. A transmission line of characteristic impedance 400 Ω is to be matched to a load of 25 Ω through a quarter wavelength line. The quarter wave line characteristic impedance must be
(a) 40 Ω (b) 100 Ω
(c) 400 Ω (d) 425 Ω
32. An air condenser of capacitance of 0.005 μ F is connected to a d.c. supply of 500 Volts, disconnected and then immerses in oil with a dielectric constant of 2.5. Energy stored in the capacitor before and after immersion, respectively is
(a) 500×10^{-4} Joules and 250×10^{-4} Joules
(b) 250×10^{-4} Joules and 500×10^{-4} Joules
(c) 625×10^{-4} Joules and 250×10^{-4} Joules
(d) 250×10^{-4} Joules and 625×10^{-4} Joules
33. In a line, the VSWR of a load is 6 dB. The reflection coefficient will be
(a) 0.033 (b) 0.33
(c) 0.66 (d) 3.3
34. $Z_L = 200 \Omega$ and it is desired that $Z_i = 50\Omega$. The quarter wave transformer should have a characteristic impedance of
(a) 100 Ω (b) 40 Ω
(c) 10.000 Ω (d) 4 Ω
35. An electric potential field is produced in air by point charges 1 μ C and 4 μ C located at $(-2, 1, 5)$ and $(1, 3, -1)$ respectively. The energy stored in the field is
(a) 2.57 mJ (b) 5.14 mJ
(c) 10.28 mJ (d) 12.50 mJ
36. What is the magnetic dipole moment in $A \cdot m^2$ for a square current loop having the vertices at the points $A(10, 0, 0)$, $B(0, 10, 0)$, $C(-10, 0, 0)$ and $D(0, -10, 0)$ and with current 0.01 A flowing in the sense ABCDA?
(a) $2 \vec{a}_z$ (b) $-2 \vec{a}_z$
(c) $4 \vec{a}_z$ (d) $4(\vec{a}_x + \vec{a}_y)$
37. For an electric field $E = E_0 \sin \omega t$, what is the phase difference between the conduction current and the displacement current?
(a) 0° (b) 45°
(c) 90° (d) 180°
38. For sea water with $\sigma = 5$ mho/m and $\epsilon_r = 80$, what is the distance for which radio signal can be transmitted with 90% attenuation at 25 kHz?
(a) 0.322 m (b) 3.22 m
(c) 32.2 m (d) 322 m
39. The electric field of a wave propagating through a lossless medium ($\mu_o, 81 \epsilon_o$) is $\vec{E} = 10 \cos(6\pi \times 10^8 t - \beta x) \vec{a}_y$. What is the phase constant β of the wave?
(a) 2π rad/m (b) 9π rad/m
(c) 18π rad/m (d) 81π rad/m

40. If the phase velocity of a plane wave in a perfect dielectric is 0.4 times its value in free space, then what is the relative permittivity of the dielectric?
 (a) 6.25 (b) 4.25
 (c) 2.5 (d) 1.25
41. The potential (scalar) distribution is given as $V = 10y^4 + 20x^3$. If ϵ_0 the permittivity of free space, what is the charge density ρ at the point (2, 0)?
 (a) $-200 \epsilon_0$ (b) $-200/\epsilon_0$
 (c) $200 \epsilon_0$ (d) $-240 \epsilon_0$
42. To avoid grating lobe at any arbitrary angle of scan using a uniformly spaced array of identical radiators with interelement spacing ' d ' and operating wavelength ' λ ', which one of the following conditions should be satisfied?
 (a) $d < 0.5 \lambda$ (b) $d > \lambda$
 (c) $0.7 \lambda \leq d < 2\lambda$ (d) $0.5 \lambda < d < \lambda$
43. A filamentary current of 10π A flows in the negative z -direction. The magnetic field at (0, 5, 0) is
 (a) $\hat{a}_x$ A/m (b) $\hat{a}_y$ A/m
 (c) $\hat{a}_z$ A/m (d) $(\hat{a}_x + \hat{a}_y)$ A/m
44. If the open-and short-circuit input impedances of a lossless line are respectively Z_1 and Z_2 , its characteristic impedance will be
 (a) $Z_1 + Z_2$ (b) $\sqrt{Z_1^2 + Z_2^2}$
 (c) $\frac{Z_1^2 + Z_2^2}{Z_1 + Z_2}$ (d) $\sqrt{Z_1 Z_2}$
45. The directive gain of an antenna is 30 dB. If the antenna radiates 7.5 kW, the power density at a distance of 40 km will be
 (a) $\frac{7.5 \times 10^3}{40 \times 10^3} \times 30 \text{ W/m}^2$
 (b) $\frac{7.5 \times 10^3 \times 30}{4\pi (40 \times 10^3)^2} \text{ W/m}^2$
 (c) $\frac{7.5 \times 10^3 \times 1000}{4\pi (40 \times 10^3)^2} \text{ W/m}^2$
 (d) $\frac{7.5 \times 10^3}{(40 \times 10^3)^2} \times 30 \text{ W/m}^2$
46. If a uniform plane wave propagating in the direction $(4\hat{a}_x - 2\hat{a}_y + \hat{a}_z)$ has its E field in the direction $(4\hat{a}_x - 2K\hat{a}_y + 4K\hat{a}_z)$, the value of K must be
 (a) 2 (b) -2
 (c) 1 (d) Zero
47. If $\vec{B} = B_0 \cos \omega t \hat{a}_y$ and $\vec{E} = \hat{a}_x E_x$, then
 (a) $E_x = 0$ (b) $E_x = +B_0 \omega \sin \omega t$
 (c) $E_x = +B_0 \cos \omega t$ (d) $E_x = \frac{1}{2} B_0 \omega^2 \sin \omega t$
48. A voltage of $50 \sin 1000 t$ V is applied across a parallel plate capacitor area of 5 cm^2 and plate separation gap of 5 mm. If the dielectric material in the capacitor has $\epsilon = 2\epsilon_0$, then the capacitor current (in Amperes) will be
 (a) $\frac{10^4}{\epsilon_0} \cos 10^3 t$ (b) $\epsilon_0 10^4 \cos 10^3 t$
 (c) $\frac{10^4}{\epsilon_0} \sin 10^3 t$ (d) $\epsilon_0 10^4 \sin 10^3 t$
49. The torque on a dipole consisting of $1 \mu\text{C}$ of charge at (0, 0, 10^{-3}) m and $-1 \mu\text{C}$ charge at (0, 0, -10^{-3}) m in an electric field $\vec{E} = 10^3 (2\hat{a}_x - \hat{a}_y - 2\hat{a}_z) \text{ V/m}$. The value of torque would be
 (a) $2 \times 10^{-6} (\hat{a}_x + 2\hat{a}_y) \text{ N-m}$
 (b) $10^{-6} (\hat{a}_x + 2\hat{a}_y) \text{ N-m}$
 (c) $-4 \times 10^{-6} \text{ N-m}$
 (d) $-2 \times 10^{-6} (\hat{a}_x + 2\hat{a}_y) \text{ N-m}$
50. The region $z \leq 0$ is a dielectric of relative permittivity 2 while the region $z \geq 0$ is a dielectric of relative permittivity 5. If the electric field intensity in region $z \leq 0$ is $\vec{E} = 10 \hat{a}_z \text{ kV/m}$ the potential difference between (0, 0, -10^{-3}) m and (0, 0, 10^{-3}) m will be
 (a) zero (b) 70 V
 (c) 20 V (d) 14 V
51. An infinite plane sheet of uniform surface charge density $\sigma \text{ C/m}^2$ is lying in the $x-y$ plane. The electric field $\vec{E}$ at a point $P(0, 0, z)$ above the sheet ($z > 0$) would be (ϵ_0 is the free space permittivity)
 (a) $\vec{E} = \frac{\sigma}{2\epsilon_0} \hat{a}_z$ (b) $\vec{E} = \frac{\sigma}{\epsilon_0} \hat{a}_z$
 (c) $\vec{E} = \frac{\hat{a}_z \sigma}{4\pi\epsilon_0 z^2}$ (d) $\vec{E} = \frac{\sigma^2}{4\pi\epsilon_0 z^2} \hat{a}_z$
52. If the vector $\vec{B} = x^2 \hat{a}_x - xy \hat{a}_y - Kxz \hat{a}_z$ represents a magnetic field, the value of the constant K must be
 (a) 0 (b) 1
 (c) 2 (d) 3
53. The region $z < 0$ has $\mu_r = 6$ and the region $z > 0$ has $\mu_r = 4$. If the magnetic flux density in region $z > 0$ is $5\hat{a}_x + 8\hat{a}_z \text{ mWb/m}^2$, the magnetic field intensity in region $z < 0$ would be
 (a) $\frac{5\hat{a}_x + 8\hat{a}_z}{4\mu_0} \text{ mA/m}$ (b) $\frac{5\hat{a}_x + 8\hat{a}_z}{6\mu_0} \text{ mA/m}$
 (c) $\frac{5\hat{a}_x}{4\mu_0} + \frac{8\hat{a}_z}{6\mu_0} \text{ mA/m}$ (d) $\frac{5\hat{a}_x}{6\mu_0} + \frac{8\hat{a}_z}{4\mu_0} \text{ mA/m}$
54. A solid cylindrical conductor of radius ' R ' carrying a current ' I ' has a uniform current density. The magnetic field intensity ' H ' inside the conductor at the radial distance ' r ' ($r > R$) is
 (a) Zero (b) $\frac{1}{2\pi r}$
 (c) $\frac{Ir}{2\pi R^2}$ (d) $\frac{IR^2}{2\pi r^3}$
55. When air pocket is trapped inside a dielectric of relative permittivity ' S ', for a given applied voltage across the dielectric,

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the ratio of stress in the air pocket to that in the dielectric is equal to

- (a) $\frac{1}{5}$ (b) 5
(c) $1 + 5$ (d) $5 - 1$

56. A circuit loop is rotating about the y -axis as a diameter in a magnetic field $\vec{B} = B_0 \sin \omega t \hat{a}_x$ Wb/m^2 . The induced emf in the loop is
(a) Due to transformer emf only
(b) Due to motional emf only
(c) Due to a combination of transformer and motional emf
(d) Zero

57. In the relation $S = \frac{1 + |\Gamma|}{1 - |\Gamma|}$; the values of S and Γ (where S stands for wave ratio and Γ is reflection coefficient), respectively, vary as
(a) 0 to 1 and -1 to 0 (b) 1 to ∞ and -1 to $+1$
(c) -1 to $+1$ and 1 to μ (d) -1 to 0 and 0 to 1

58. Three media are characterized by

1. $\epsilon_r = 8, \mu_r = 2, \sigma = 0$
2. $\epsilon_r = 1, \mu_r = 9, \sigma = 0$
3. $\epsilon_r = 4, \mu_r = 4, \sigma = 0$

ϵ_r is relative permittivity, μ_r is relative permeability and σ is conductivity. The values of the intrinsic impedances of the media 1, 2 and 3 respectively are

- (a) $188 \Omega, 377 \Omega$ and 1131Ω
(b) $377 \Omega, 1131 \Omega$ and 188Ω
(c) $188 \Omega, 1131 \Omega$ and 377Ω
(d) $1131 \Omega, 188 \Omega$ and 377Ω

59. A plane em wave $(\vec{E}_i, \vec{H}_i)$ travelling in a perfect dielectric medium of surge impedance. 'Z' strikes normally an infinite perfect dielectric medium of surge impedance $2Z$. If the refracted em wave is $(\vec{E}_r, \vec{H}_r)$, the ratios of $\frac{E_i}{E_r}$ and $\frac{H_i}{H_r}$ are respectively
(a) $1/3$ and $3/2$ (b) $3/2$ and $1/3$
(c) $3/4$ and $3/2$ (d) $3/4$ and $2/3$

60. The relation between electric intensity E , voltage applied V and the distance d between the plates of a parallel plate condenser is

- (a) $E = \frac{V}{d}$ (b) $E = V \times d$
(c) $E = \frac{V}{(d)^2}$ (d) $E = V \times (d)^2$

61. Ohm's law in point form in field theory can be expressed as

- (a) $V = RI$ (b) $\vec{j} = \frac{\vec{E}}{\sigma}$
(c) $\vec{J} = \sigma \vec{E}$ (d) $R = \frac{\rho \ell}{A}$

62. The magnetic flux through each turn of a 100 run coil is $(t^3 - 2t)$ milli-webers where t is in seconds. The induced emf at $(t = 2s)$ is

- (a) 1 V (b) -1 V
(c) 0.4 V (d) -0.4 V

63. If a vector field $\vec{B}$ is solenoidal, which of these is true?

- (a) $\oint_{\ell} \vec{B} \cdot d\vec{\ell} = 0$ (b) $\oint_s \vec{B} \cdot d\vec{s} = 0$
(c) $\nabla \times \vec{B} = 0$ (d) $\lambda = \frac{5}{3}$

64. For linear isotropic materials, both $\vec{E}$ and $\vec{H}$ have the time dependence $e^{j\omega t}$ and regions of interest are free of charges. The value of $\vec{\nabla} \times \vec{H}$ is given by

- (a) $\sigma \vec{E}$ (b) $j\omega \epsilon \vec{E}$
(c) $\sigma \vec{E} + j\omega \epsilon \vec{E}$ (d) $\sigma \vec{E} - j\omega \epsilon \vec{E}$

65. Which of the following equations is/are not Maxwell's equation(s)?

1. $\nabla \cdot \vec{j} = -\frac{\partial \rho_v}{\partial t}$
2. $\nabla \cdot \vec{D} = \rho_v$
3. $\nabla \cdot \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
4. $\oint \vec{H} \cdot d\vec{l} = \oint_s \left(\sigma \vec{E} + \epsilon \frac{\partial \vec{E}}{\partial t} \right) \cdot d\vec{s}$

Select the correct answer using the codes given below:

- (a) 2 and 4 (b) alone
(c) 1 and 3 (d) 1 and 4

66. In free space

$$\vec{H}(z, t) = 0.10 \cos(4 \times 10^7 t - \beta z) \hat{a}_x \text{ A/m.}$$

The expression for $\vec{E}(z, t)$ is

- (a) $\vec{E}(z, t) = 37.7 \cos(4 \times 10^7 t - \beta z) \hat{a}_y$
(b) $\vec{E}(z, t) = 2.65 \times 10 \cos(4 \times 10^7 t - \beta z) \hat{a}_z$
(c) $\vec{E}(z, t) = 37.7 \cos(4 \times 10^7 t - \beta z) \hat{a}_x$
(d) $\vec{E}(z, t) = -37.7 \cos(4 \times 10^7 t - \beta z) \hat{a}_y$

67. In free space $\vec{E}(z, t) = 50 \cos(\omega t - \beta z) \hat{a}_x$ V/m and

$$\vec{H}(z, t) = \frac{5}{12\pi} \cos(\omega t - \beta z) \hat{a}_y \text{ A/m. The average power}$$

crossing a circuit area of radius $\sqrt{24}$ m in plane $z = \text{constant}$ is

- (a) 200 W (b) 250 W
(c) 300 W (d) 350 W

68. A copper wire carries a conduction current of 1.0 A at 50 Hz. For copper wire $\epsilon = \epsilon_0, \mu = \mu_0, \sigma = 5.8 \times 10 \text{ mho/m}$. What is the displacement current in the wire?

- (a) 2.8×10 A
(b) 4.8×10 A
(c) 1 A
(d) It cannot be calculated with the given data

69. A transmission line has R, L, G and C distributed parameters per unit length of the line. γ is the propagation constant of the

lines. Which expression gives the characteristic impedance of the line?

- (a) $\frac{\gamma}{R + j\omega L}$ (b) $\frac{R + j\omega L}{\gamma}$
 (c) $\frac{G + j\omega C}{\gamma}$ (d) $\sqrt{\frac{G + j\omega C}{R + j\omega L}}$

70. Which of the following equation is correct?

- (a) $a_x \times a_x = |a_x|^2$
 (b) $(a_x \times a_y) + (a_y \times a_x) = 0$
 (c) $a_x \times (a_y \times a_z) = a_x \times (a_z \times a_y)$
 (d) $a_r \cdot a_\theta + a_\theta \cdot a_r = 0$

71. An electromagnetic field is said to be conservative when

- (a) $\nabla^2 E = \mu \epsilon \frac{\partial^2 E}{\partial t^2}$
 (b) $\nabla^2 H = \mu \epsilon \frac{\partial^2 H}{\partial t^2}$
 (c) Curl of the field zero
 (d) Divergence of the field is zero

72. A charge is uniformly distributed throughout the sphere of radius a . Taking the potential at infinity as zero, the potential at $r = b < a$ is

- (a) $-\int_{\infty}^b \frac{Qr}{4\pi\epsilon_0 a^3} dr$
 (b) $-\int_{\infty}^b \frac{Qr}{4\pi\epsilon_0 r^2} dr$
 (c) $-\int_{\infty}^b \frac{Qr}{4\pi\epsilon_0 a^3} dr - \int_a^b \frac{Qr}{4\pi\epsilon_0 a^3} dr$
 (d) $-\int_{\infty}^a \frac{Qr}{4\pi\epsilon_0 r^2} dr$

73. Which one of the following pairs is not correctly matched?

- (a) Gauss's Theorem $\oint_S \vec{D} \cdot d\vec{s} = \int_V \nabla \cdot \vec{D} dV$
 (b) Gauss's Law $\oint_S \vec{D} \cdot d\vec{s} = \int_V \rho dV$
 (c) Coulomb's Law $V = \frac{-d\phi_m}{dt}$
 (d) Stokes's Theorem $\oint_l \vec{\xi} \cdot d\vec{l} = \int_s (\nabla \times \vec{\xi}) \cdot d\vec{s}$

74. Which one of the following formula is not correct for the boundary by magnetic materials?

- (a) $B_{n1} = B_{n2}$
 (b) $B_2 = \sqrt{B_{n2}^2 + B_{t2}^2}$
 (c) $H_1 = H_{n1} + H_{t1}$
 (d) $\hat{a}_{n21} \times (-\vec{H}_1 - \vec{H}_2) = \vec{K}$, where $\hat{a}_{n21}$ is a unit vector normal to the interface and directed from region 2 to region 1

75. Maxwell equation $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ is represented in integral form as

- (a) $\oint \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \oint \vec{B} \cdot d\vec{l}$ (b) $\oint \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \oint \vec{B} \cdot d\vec{s}$
 (c) $\oint \vec{E} \times d\vec{l} = \frac{\partial}{\partial t} \oint \vec{B} \cdot d\vec{l}$ (d) $\oint \vec{E} \times d\vec{l} = \frac{\partial}{\partial t} \oint \vec{B} \cdot d\vec{s}$

76. Given that

$\vec{H} = 0.5 e^{-0.1x} \sin(10^6 t - 2x) \hat{a}_z \left(\frac{A}{m} \right)$, which one of following statements is not correct?

- (a) Wave is linearly polarized along $\hat{a}_z$
 (b) The velocity of the wave is 5×10^5 m/s
 (c) The complex propagation constant is $(0.1 - 2j)$
 (d) The wave is travelling along $\hat{a}_x$

77. For a conducting medium with conductivity σ , permeability μ , and permittivity ϵ , then the skin depth for an electromagnetic signal at an angular frequency ω is proportional of

- (a) σ (b) $1/\omega$
 (c) $\frac{1}{\sqrt{\sigma}}$ (d) $\frac{1}{\mu}$

78. The electric field of a uniform plane wave is given by

$$\vec{E} = 10 \sin(\omega t - \pi z) \hat{a}_x + 10 \cos(\omega t - \pi z) \hat{a}_y \frac{V}{m}$$

The polarization of the wave is

- (a) Circular (b) Elliptical
 (c) Linear (d) Undefined

79. Consider the following statements:

Characteristic impedance of a transmission line is given by

- $\sqrt{\frac{R + j\omega L}{G + j\omega C}}$, R , L , G and C are line constants
- $\sqrt{Z_{oc} Z_{sc}}$, Z_{oc} and Z_{sc} are the open and short circuit impedance of the line
- $\frac{V'}{I'}$

(and are the voltage and current of the wave travelling in the positive direction)

Which of these are correct?

- (a) 1, 2 and 3 (b) 1 and 2
 (c) 2 and 3 (d) 1 and 3

80. A loss-less transmission line of characteristic impedance Z_0

and $l < \frac{\lambda}{4}$ is terminated at the load end by a short circuit. Its input impedance Z_s is

- (a) $Z_s = -jZ_0 \tan \beta l$ (b) $Z_s = jZ_0 \cot \beta l$
 (c) $Z_s = jZ_0 \tan \beta l$ (d) $Z_s = -jZ_0 \cot \beta l$

81. A loss-less transmission line with characteristic impedance of 600 ohms is terminated in a purely resistive load of 900 ohms. The reflection coefficient is

- (a) 0.2 (b) 0.5
 (c) 0.667 (d) 1.5

5.32 ■ Electromagnetic Theory

82. What is the force experienced per unit length by a conductor carrying 5 A current in positive Z direction and placed in a magnetic field $\vec{B} = (3\vec{a}_x + 4\vec{a}_y)$?
- (a) $150\vec{a}_x = 20\vec{a}_y$ (b) $-20\vec{a}_x + 15\vec{a}_y$ N/m
(c) $20\vec{a}_x - 15\vec{a}_y$ N/m (d) $-20\vec{a}_x - 20\vec{a}_y$ N/m
83. Plane $z = 0$ m carries surface charge density 20 nC/m^2 . What is the electric field at the origin?
- (a) $-10\vec{a}_z$ v/m (b) $-18\pi\vec{a}_z$ v/m
(c) $72\pi\vec{a}_z$ v/m (d) $-360\pi\vec{a}_z$ N/m
84. Two extensive homogenous isotropic dielectrics meet on a plane $z = 0$. For $z \geq 0$, $\epsilon_{r1} = 4$ and for $z \leq 0$, $\epsilon_{r2} = 2$. A uniform electric field exists at $z \geq 0$ as $\vec{E}_1 = 5\vec{a}_x - 2\vec{a}_y + 3\vec{a}_z$ kv/m. What is the value of $\vec{E}_2$ in the region $z \leq 0$?
- (a) $3\vec{a}_z$ (b) $5\vec{a}_x - 2\vec{a}_y$
(c) $6\vec{a}_x$ (d) $\vec{a}_x - \vec{a}_y - \vec{a}_z$
85. A flat slab of dielectric, $\epsilon_r = 5$ is placed normal to a uniform field with a flux density $D = 1$ coulomb/m². The slab is uniformly polarized. What is the polarization P of the slab in coulomb/m²?
- (a) 0.8 (b) 1.2
(c) 4 (d) 6
86. Which one of the following is the correct electromagnetic wave equation in terms of vector potential $\vec{A}$?
- (a) $\nabla^2 \vec{A} - \frac{\partial^2 \vec{A}}{\partial t^2} = -\vec{J}$
(b) $\nabla^2 \vec{A} - \frac{\mu}{\epsilon} \frac{\partial^2 \vec{A}}{\partial t^2} = -\mu \vec{J}$
(c) $\nabla^2 \vec{A} - \frac{\partial^2 \vec{A}}{\partial t^2} = -\mu \vec{J}$
(d) $\nabla^2 \vec{A} - \mu\epsilon \frac{\partial^2 \vec{A}}{\partial t^2} = -\mu \vec{J}$
87. Which one of the following statements is correct?
For a lossless dielectric medium, the phase constant for a travelling wave, β is proportional to
- (a) ϵ_r (b) $\sqrt{\epsilon_r}$
(c) $\frac{1}{\epsilon_r}$ (d) $\frac{1}{\sqrt{\epsilon_r}}$
88. In a lossless medium, the intrinsic impedance $\eta = 60\pi$ and $\mu_r = 1$. What is the value of the dielectric constant ϵ_r ?
- (a) 2 (b) 1
(c) 4 (d) 8
89. A lossless transmission line of length 50 cm with $L = 10 \mu\text{H/m}$, $C = 40 \text{ pF/m}$ is operated at 30 MHz. What is the electric length (βl)?
- (a) 20λ (b) 0.2λ
(c) 108° (d) 40π
90. Which one of the following is the correct expression for the propagation constant in a transmission line?

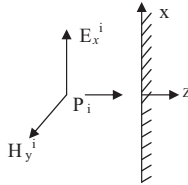
- (a) $(R - j\omega L)(G - j\omega C)$
(b) $\sqrt{\frac{R - j\omega L}{G - j\omega C}}$
(c) $\sqrt{\frac{R + j\omega L}{G + j\omega C}}$
(d) $\sqrt{(R + j\omega L)(G + j\omega C)}$

91. For a line of characteristic impedance Z_o terminated in a load of Z_R such that $Z_R = Z_o/3$, what is the reflection coefficient Γ_L ?
- (a) 1/3 (b) 2/3
(c) -1/3 (d) -1/2
92. A transmission line has R, L, G, C distributed parameters per unit length of line. If γ is the propagation constant of the line, which one of the following expressions represents the characteristic impedance of the line?
- (a) $\frac{\gamma}{R + j\omega L}$ (b) $\frac{R + j\omega L}{\gamma}$
(c) $\frac{G + j\omega C}{\gamma}$ (d) $\sqrt{\frac{G + j\omega C}{R + j\omega L}}$
93. In free space, if $\rho = 0$, the Poisson's equation becomes
- (a) Maxwell's divergence equation $\nabla \cdot \vec{B} = 0$
(b) Laplacian equation $\nabla^2 V = 0$
(c) Kirchhoff's voltage equation $\sum V = 0$
(d) None of the above
94. What is the magnetic field due to an infinite linear current carrying conduction?
- (a) $H = \frac{\mu I}{2\pi r}$ A/m (b) $H = \frac{I}{2\pi r}$ A/m
(c) $H = \frac{\mu I}{2r}$ A/m (d) $H = \frac{I}{r}$ A/m
95. Equation $\nabla \cdot \vec{B} = 0$ is based on
- (a) Gauss's Law (b) Lenz's Law
(c) Ampere's Law (d) Continuity Equation
96. Sphere of radius a with a uniform charge density $\rho_v \text{ C/m}^3$ shall have electric flux density at $r = a$, equal to
- (a) $\frac{a}{3} \rho_v \hat{r} \text{ C/m}^2$ (b) $\frac{1}{3} \rho_v \hat{r} \text{ C/m}^2$
(c) $a \rho_v \hat{r} \text{ C/m}^2$ (d) $\frac{a}{4} \rho_v \hat{r} \text{ C/m}^2$
97. Which of the following is zero as applied to electromagnetic fields?
- (a) $\text{Grad div } \vec{A}$ (b) $\text{div grad } V$
(c) $\text{div curl } \vec{A}$ (d) $\text{curl curl } \vec{A}$
98. What is the force on a unit charge moving with velocity $\vec{v}$ in presence of electric field $\vec{E}$ and magnetic field $\vec{B}$?
- (a) $\vec{E} - \vec{v} \times \vec{B}$ (b) $\vec{E} + \vec{v} \times \vec{B}$
(c) $\vec{E} + \vec{B} \times \vec{v}$ (d) $\vec{E} + \vec{v} \times \vec{B}$

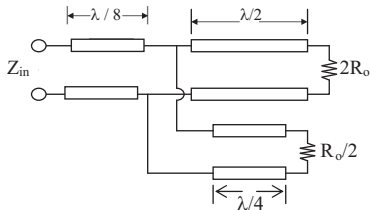
99. Six capacitors of different capacitances C_1, C_2, C_3, C_4, C_5 , and C_6 are connected in series. $C_1 > C_2 > C_3 > C_4 > C_5 > C_6$. What is the total capacitance almost equal to?
- (a) C_1 (b) C_2
 (c) C_4 (d) C_6
100. Plane $y = 0$ carries a uniform current density $30\hat{k}$ mA/m. A t $(1, 20 - 2)$. What is the magnetic field intensity?
- (a) $-15\hat{i}$ mA/m (b) $15\hat{i}$ mA/m
 (c) $18.85\hat{j}$ mA/m (d) $25\hat{i}$ mA/m

LEVEL 3

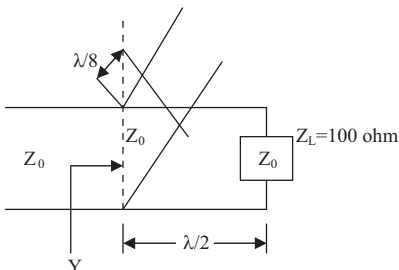
1. A plane wave is incident normally on a perfect conductor field and pointing vector as show in the figure. Here E_x^i , H_y^i and $\vec{p}_i$ are electric field, magnetic field and pointing vector respectively, for the incident wave. The reflected wave should have.



- (a) $E_x^r = -E_x^i$ (b) $H_y^r = -H_y^i$
 (c) $\vec{p}^r = -\vec{p}_i$ (d) $E_x^r = E_x^i$
2. All transmission line sections in the figure have a characteristic impedance $R_0 + j0$. The input impedance Z_{in} equals

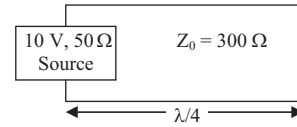


- (a) $(2/3) R_0$ (b) R_0
 (c) $(3/2) R_0$ (d) $2 R_0$
3. A short-circuited stub is shunt connected to a transmission line as shown in the figure. If $Z_0 = 50$ ohm, the admittance Y seen at the junction of the stub and the transmission line is

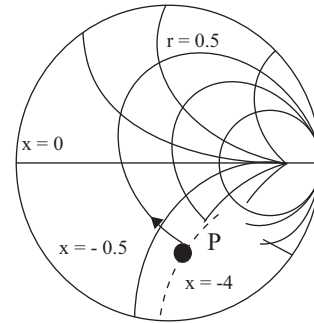


- (a) $(0.01 - j0.02)$ mho (b) $(0.02 - j0.01)$ mho
 (c) $(0.04 - j0.02)$ mho (d) $(0.02 + j0)$ mho

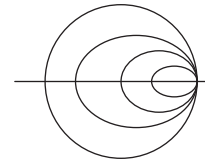
4. Consider a 300Ω , quarter-wave long (at 1 GHz) transmission lines as shown in the figure. It is connected to a $10V$, 50Ω source at one end and is left open circuited at the other end. The magnitude of the voltage at the open end of the line is



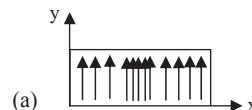
- (a) 10 V (b) 5 V
 (c) 60 V (d) $60/7$ V
5. Consider an impedance $Z = R + jX$ marked with point P in an impedance Smith chart as shown in the figure. The movement from point P along a constant resistance circle in the clockwise direction by an angle 45° is equivalent to

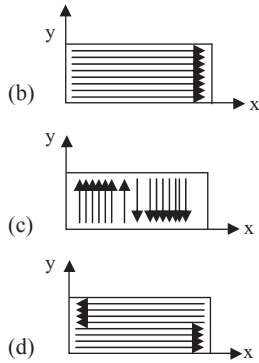


- (a) Adding an inductance in series with Z
 (b) Adding a capacitance in series with Z
 (c) Adding an inductance in shunt across Z
 (d) Adding a capacitance in shunt across Z
6. Many circle are drawn in a Smith chart for transmission line calculations. The circles shown in the figure represent

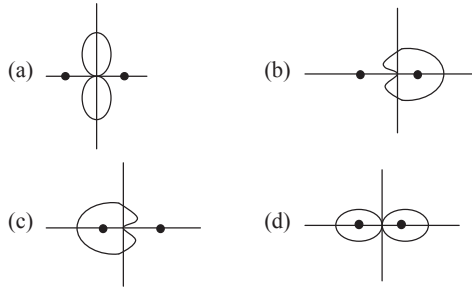


- (a) Unit circles
 (b) Constant resistance circles
 (c) Constant reactance circles
 (d) Constant reflection coefficient circles
7. Which one of the following does represent the electric field lines for the TE_{02} mode in the cross-section of a hollow rectangular metallic wave-guide?

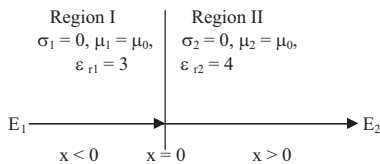




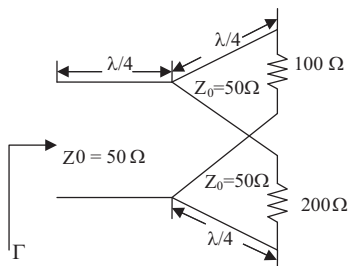
8. Two identical and parallel dipole antennas are kept apart by a distance of $[\lambda/4]$ in the H-plane. They are fed with equal currents but the right most antenna has a phase shift of $+90^\circ$. The radiation pattern is given as



9. The medium is divided into regions I and II about a $x = 0$ plane, as shown in the figure below. An electromagnetic wave with electric field $E_1 = 4 \hat{a}_x + 3 \hat{a}_y + 5 \hat{a}_z$ is incident normally on the interface from region - I. The electric field E_2 in region - II at the interface is

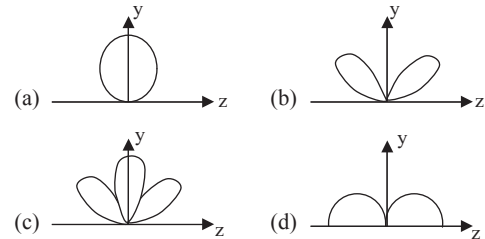


- (a) $E_2 = E_1$
 (b) $4 \hat{a}_x + 0.75 \hat{a}_y - 1.25 \hat{a}_z$
 (c) $3 \hat{a}_x + 3 \hat{a}_y + 5 \hat{a}_z$
 (d) $-3 \hat{a}_x + 3 \hat{a}_y + 5 \hat{a}_z$
10. The parallel branches of a 2-wire transmission line are terminated in 100Ω and 200Ω resistors as shown in the figure. The characteristic impedance of the line is $Z_0 = 50 \Omega$ and each section has a length of $\lambda/4$. The voltage reflection coefficient Γ at the input is

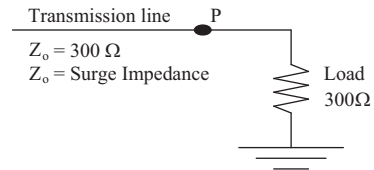


- (a) $-j\frac{7}{5}$
 (b) $\frac{-5}{7}$
 (c) $j\frac{5}{7}$
 (d) $\frac{5}{7}$

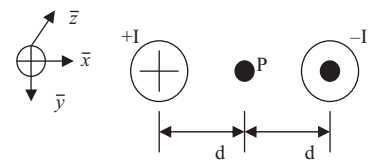
11. A $\lambda/2$ dipole is kept horizontally at a height of $\lambda_0/2$ above a perfectly conducting infinite plane. The radiation pattern in the plane of the dipole ($\vec{E}$ plane) looks approximately as



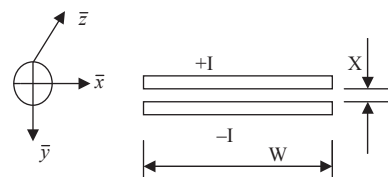
12. The reflection coefficient for the transmission line shown in the figure below at P is



- (a) $+1$
 (b) -1
 (c) 0
 (d) 0.5
13. Two conductors are carrying forward and return current of $+I$ and $-I$ as shown in the figure. The magnetic field intensity $\vec{H}$ at point P is

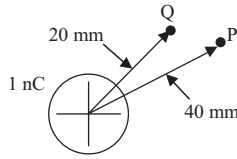


- (a) $[I/\pi d] \vec{y}$
 (b) $[I/\pi d] \vec{x}$
 (c) $[I/2\pi d] \vec{y}$
 (d) $[I/2\pi d] \vec{x}$
14. Two infinite strips of width w m in x direction as shown in the figure, are carrying forward and return currents of $+I$ and $-I$ in the z direction. The strips are separated by a distance of x m. The inductance per unit length of the configuration is measured to be L H/m. If the distance of separation between the strips is now reduced to $x/2$ m, the inductance per unit length of the configuration is

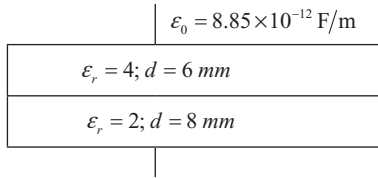


- (a) $2L$ H/m
 (b) $L/4$ H/m
 (c) $L/2$ H/m
 (d) $4L$ H/m

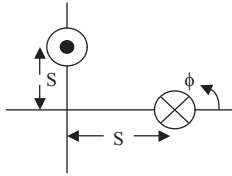
15. A point charge of $+1\text{ nC}$ is placed in a space with a permittivity of $8.85 \times 10^{-12} \text{ F/m}$ as shown in the figure. The potential difference V_{PQ} between two point P and Q at distance of 40 mm and 20 mm respectively from the point charge is



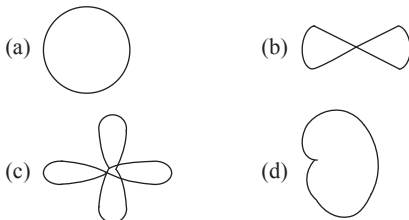
- (a) 0.22 kV (b) -225 kV
(c) -2.24 kV (d) 15 V
16. A parallel plate capacitor is shown in the figure. It is made of two square metal plates of 400 mm side. The 14 mm space between the plates is filled with two layers of dielectrics of $\epsilon_r = 4$, 6 mm thick and $\epsilon_r = 2$, 8 mm thick. Neglecting fringing of fields at the edges, the capacitance is



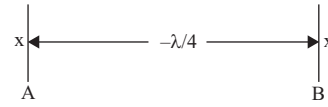
- (a) 1298 pF (b) 944 pF
(c) 354 pF (d) 257 pF
17. Two identical antennas are placed in the $\theta = \pi/2$ plane as shown in the figure. The elements have equal amplitude excitation with 180° polarity difference, operating at wavelength λ . The correct value of the magnitude of the far-zone resultant electric field strength normalized with that of a single element, both computed for $\phi = 0$, is



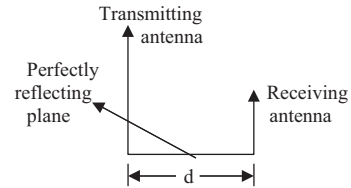
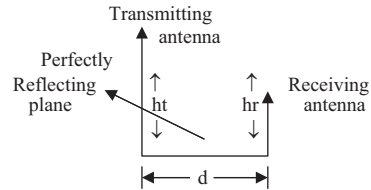
- (a) $2 \cos(2\pi S/\lambda)$ (b) $2 \sin(2\pi S/\lambda)$
(c) $2 \cos(\pi S/\lambda)$ (d) $2 \sin(\pi S/\lambda)$
18. With reference to given figure, the signal picked up by the receiving antenna can be increased by increasing
- (a) h_t only (b) h_r only
(c) Both h_t and h_r (d) neither h_t nor h_r
19. If a vertical dipole antenna is used in conjunction with a loop antenna for direction finding, the field pattern obtained will be



20. For two identical antennas A and B spaced $\lambda/4$ apart as shown in the figure, it is possible to have null radiation along the array axis on the right side of by having an excitation arrangement such that



- (a) The phase of current in antenna B lags behind that of antenna A by $\pi/2$ radians
(b) Current in the antenna are in phase
(c) The phase of current in antenna A lags behind that of antenna B by $\pi/2$ radians
(d) Current in the antenna are out of phase by π radians
21. With reference to the given figure, the signal picked up by the receiving antenna can be increased by increasing



- (a) h_t only (b) h_r only
(c) Both h_t and h_r (d) neither h_t nor h_r
22. What is the Poynting's vector on the surface of a long straight conductor of radius b and conductivity σ which carries current I in the z -direction?
- (a) $\frac{I^2}{2\sigma\pi^2 b^3} \hat{r}_r$ (b) $\frac{I^2}{2\sigma\pi^2 b^2} \hat{r}_r$
(c) $\frac{I^2}{2\sigma\pi b^2} \hat{z}$ (d) $\frac{I^2}{2\pi b} \hat{\phi}$
23. 50 Ω loss-less transmission line is terminated in 100 Ω load and is excited by a 30 MHz source of internal resistance of 50 Ω . What should be the length of the transmission line for maximum power transfer?
- (a) 5.0 m (b) 1.25 m
(c) 2.5 m (d) 10.0 m
24. A conductor having surface density σ is embedded in a dielectric medium of permittivity. The electric field in the medium is E . If it is known that the pressure p on the conductor surface is equal to the electric energy density in the medium, then p (in SI unit) is given by
- (a) $[\sigma^2/2]$ (b) $[\sigma/2\epsilon]$
(c) $[\sigma/4\pi\epsilon]$ (d) $[\sigma^2/2\epsilon]$

25. A generator of 50 ohm internal impedance and operating at 1 GHz feeds a 75 Ω load via a coaxial line of characteristic impedance 50 ohm. The voltage Standing Wave Ratio on the feed line is
 (a) 0.5 (b) 1.5
 (c) 2.5 (d) 1.75
26. A quarter wave transformer, made of air-filled coaxial line, matches two transmission lines of characteristics impedance 50 ohms and 72 ohm respectively. If the linear conductor of the coaxial line is made 10 mm in diameter, what should be the diameter of the outer conductor (approximately)?
 (a) 16 mm (b) 20 mm
 (c) 27 mm (d) 32 mm
27. The electric field vector $\vec{E}$ of a wave in free space (ϵ_0, μ_0) is given by $E = y [A \cos \omega t - (z/c)]$. Its magnetic vector $\vec{H}$ will be given by
 (a) $\hat{H} = y \left(A \sin \omega \left(t - \frac{z}{c} \right) \right)$
 (b) $\hat{H} = z \left(A \cos \omega \left(t - \frac{z}{c} \right) \right)$
 (c) $\hat{H} = x \left(-j \sqrt{\frac{\epsilon_0}{\mu_0}} A \cos \omega \left(t - \frac{z}{c} \right) \right)$
 (d) $\hat{H} = x \left(-j \sqrt{\frac{\epsilon_0}{\mu_0}} A \sin \omega \left(t - \frac{z}{c} \right) \right)$
28. For a transmission line, the open-circuit and short-circuit impedance are 20 Ω and 5 Ω respectively. Then the characteristic impedance of the line is
 (a) 100 ohms (b) 50 ohms
 (c) 25 ohms (d) 10 ohms
29. The characteristic impedance of a transmission line with inductance 0.294 $\mu\text{H/m}$ and capacitance 60 pF/m, is
 (a) 49 W (b) 60 W
 (c) 70 W (d) 140 W
30. When a dielectric is placed in electric field, the electric flux density D , electric field intensity E and polarization P are related as
 (a) $\vec{D} = \epsilon_0 \vec{E} \times \vec{P}$ (b) $\vec{D} = \epsilon_0 \vec{E} - \vec{P}$
 (c) $\vec{D} = \epsilon_0 (\vec{E} + \vec{P})$ (d) $\vec{D} = \epsilon_0 \vec{E} + \vec{P}$
31. The magnitude of the reflection coefficient of a transmission line in terms of the load and characteristic impedance is given by
 (a) $\rho = \frac{Z_L + Z_0}{Z_0 - Z_L}$ (b) $\frac{Z_0 Z_L}{Z_0 - Z_L}$
 (c) $\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$ (d) $\frac{Z_L - Z_0}{Z_0 Z_L}$
32. For a transmission line, the propagation constant, for a TEM wave traveling in it, is given by (where the symbols have the usual meanings)
 (a) $[(R + j\omega L)(G + j\omega C)]$
 (b) $[(R + j\omega L)(G + j\omega C)]^{1/2}$
 (c) $[(R - j\omega L)(G + j\omega C)]^{1/2}$
 (d) $[(R + j\omega L)(G + j\omega^2 C)]^{1/3}$
33. An electromagnetic wave is obliquely incident at the surface of a dielectric medium 2 (μ_0, ϵ_2) from dielectric medium 1 (μ_0, ϵ_1). The angle of incidence is θ_i and θ_c is the critical angle. Then the phenomenon of total reflection occurs when
 (a) $\epsilon_1 > \epsilon_2$ and $\theta_i < \theta_c$ (b) $\epsilon_1 < \epsilon_2$ and $\theta_i > \theta_c$
 (c) $\epsilon_1 < \epsilon_2$ and $\theta_i < \theta_c$ (d) $\epsilon_1 > \epsilon_2$ and $\theta_i > \theta_c$
34. Which one of the following statements is correct?
 (a) $\nabla \cdot \hat{J} + \frac{d\rho}{dt} = 0$ (b) $\nabla \times \hat{J} + \frac{d^2\rho}{dt^2} = 0$
 (c) $\nabla \cdot \hat{J} + \frac{d^2\rho}{dt^2} = 0$ (d) $\nabla \times \hat{J} + \frac{d\rho}{dt} = 0$
35. A circular coil of 100 turns and effective radius of 10 cm carries a current of 0.1 A. Its magnetic dipole moment in A-m² is
 (a) 0.0001 π (b) 0.001 π
 (c) 0.01 π (d) 0.1 π
36. On a resistively terminated high frequency loss-less transmission line fed by a 500MHz source, the VSWR is found to be equal to 2 and the first voltage minimum is measured at 30 cm from the load end. What is the value of the "normalized" load resistance?
 (a) 3 (b) 2
 (c) 1/2 (d) 1/4
37. A 75 ohm transmission line is first short terminated and the minima locations are noted. When a resistive load R_L replaces the short, the minima locations are not altered and the VSWR is measured to be 3. What is the value of R_L ?
 (a) 25 Ω (b) 50 Ω
 (c) 225 Ω (d) 250 Ω
38. Maxwell's divergence equation for the electric field is
 (a) $\nabla \cdot E = [\rho/\epsilon_0]$ (b) $\nabla \cdot E = [\rho/2\pi\epsilon_0]$
 (c) $\nabla \times E = [\rho/\epsilon_0]$ (d) $\nabla \cdot E = [-\rho/\epsilon_0]$
39. An electric charge of 100 coulombs is enclosed in a sphere of radius 100 m. The electric displacement density (in coulomb/m²) D is
 (a) 0.0833 (b) 0.833
 (c) 1.666 (d) 10
40. If an isolated conducting sphere in air has radius = $[1/4\pi\epsilon_0]$ its capacitance
 (a) zero (b) 1 F
 (c) 4 π F (d) 0 F
41. Poisson's equation for an inhomogeneous medium is
 (a) $\nabla^2 V = -\rho/\epsilon$ (b) $\nabla \cdot (\nabla V) = -\rho$
 (c) $\nabla^2 (V) = -\rho$ (d) $\nabla \cdot (\nabla V) = -\rho$
42. A 75 ohm transmission line is to be terminated in two resistive loads R_1 and R_2 such that the standing patterns in the two cases have the same SWR. To obtain the desired result, the values of R_1 and R_2 (in ohms) should be
 (a) 250 and 200 respectively
 (b) 225 and 25 respectively
 (c) 100 and 150 respectively
 (d) 50 and 125 respectively

43. The input impedance of a lossless transmission line is 100 ohms when terminated in a short-circuit, and 64 ohms when terminated in and open circuit. The characteristic impedance of the line is
(a) 80 Ω (b) 164 Ω
(c) 36 Ω (d) 64 Ω
44. For a quarter wavelength ideal transmission line of characteristic impedance 50 ohms and load impedance 100 ohms, the input impedance will be
(a) 25 Ω (b) 50 Ω
(c) 100 Ω (d) 150 Ω
45. A loss-less line having characteristic impedance Z_0 is terminated in a pure reactance of value $-jZ_0$. The VSWR of the line will be
(a) 10 (b) 2
(c) 1 (d) infinite
46. On a slotted line terminated in a load, the minima of the standing wave pattern measured by a square-law device, are located at (on a cm scale) 9.5, 11.0, 12.5 and 14.0. At 10.95 and 11.05 the detected level being twice the minimum level. The VSWR on the line is
(a) 10 (b) 20
(c) 30 (d) 50
47. An infinite plane $Z = 10\text{ m}$ carries a uniformly distributed charge of density 2 nC/m^2 . The electric field intensity at the origin is
(a) $0.2 a_z\text{ n V/m}$ (b) $2 a_z\text{ n V/m}$
(c) $-2 a_z\text{ n V/m}$ (d) $-36 \pi a_z\text{ V/m}$
48. The skin depth of copper is found to be $66\mu\text{m}$ at 1MHz at a certain temperature. At the same temperature and at 2 MHz, the skin depth would be approximately
(a) $47\mu\text{m}$ (b) $33\mu\text{m}$
(c) $92\mu\text{m}$ (d) $122\mu\text{m}$
49. An isolated sphere in air has a radius equal to $[1/(4\pi\epsilon_0)]$ meter; its capacitance will be
(a) πF (b) $1 F$
(c) $4\pi F$ (d) $1/4\pi F$
50. The torque (in N-m) acting on a circular current loop of radius 1mm in the xy -plane, connected at the origin and with current 0.1. A flowing in the sense of increasing ϕ in a magnetic field $\vec{B} = 10^{-5} (2\hat{a}_x - 2\hat{a}_y + \hat{a}_z)\text{ Wb/m}^2$ is
(a) $-2 \times 10^{-12} (2\hat{a}_x - 2\hat{a}_y + \hat{a}_z)$
(b) $2 \times 10^{-12} \pi (\hat{a}_x + 2\hat{a}_y)$
(c) $10^{-12} \pi$
(d) $-10^{-12} \pi$

ANSWER KEYS

LEVEL 1

1. (a)	2. (c)	3. (d)	4. (a)	5. (b)	6. (d)	7. (b)	8. (d)	9. (c)	10. (d)
11. (b)	12. (b)	13. (c)	14. (c)	15. (d)	16. (b)	17. (a)	18. (d)	19. (a)	20. (b)
21. (d)	22. (a)	23. (c)	24. (c)	25. (a)	26. (b)	27. (a)	28. (a)	29. (c)	30. (a)
31. (a)	32. (c)	33. (c)	34. (b)	35. (b)	36. (c)	37. (a)	38. (a)	39. (b)	40. (c)
41. (a)	42. (b)	43. (b)	44. (c)	45. (b)	46. (b)	47. (a)	48. (a)	49. (c)	50. (c)
51. (b)	52. (c)	53. (a)	54. (b)	55. (c)	56. (a)	57. (b)	58. (a)	59. (d)	60. (c)
61. (b)	62. (a)	63. (a)	64. (d)	65. (d)	66. (d)	67. (c)	68. (d)	69. (b)	70. (c)
71. (a)	72. (b)	73. (b)	74. (c)	75. (d)	76. (c)	77. (c)	78. (a)	79. (b)	80. (b)
81. (a)	82. (b)	83. (c)	84. (b)	85. (c)	86. (d)	87. (d)	88. (b)	89. (b)	90. (c)
91. (d)	92. (b)	93. (b)	94. (c)	95. (b)	96. (d)	97. (a)	98. (b)	99. (b)	100. (a)

LEVEL 2

1. (b)	2. (c)	3. (d)	4. (d)	5. (c)	6. (b)	7. (b)	8. (a)	9. (a)	10. (b)
11. (d)	12. (d)	13. (c)	14. (d)	15. (d)	16. (b)	17. (c)	18. (d)	19. (d)	20. (b)
21. (a)	22. (a)	23. (b)	24. (c)	25. (a)	26. (d)	27. (c)	28. (c)	29. (b)	30. (b)
31. (b)	32. (c)	33. (b)	34. (a)	35. (b)	36. (c)	37. (c)	38. (b)	39. (c)	40. (a)
41. (d)	42. (a)	43. (a)	44. (d)	45. (b)	46. (b)	47. (d)	48. (b)	49. (a)	50. (d)
51. (a)	52. (b)	53. (c)	54. (c)	55. (b)	56. (c)	57. (b)	58. (c)	59. (c)	60. (a)
61. (c)	62. (b)	63. (b)	64. (c)	65. (c)	66. (d)	67. (b)	68. (b)	69. (b)	70. (b)
71. (c)	72. (c)	73. (a)	74. (b)	75. (b)	76. (c)	77. (c)	78. (a)	79. (a)	80. (c)
81. (a)	82. (b)	83. (d)	84. (c)	85. (a)	86. (d)	87. (c)	88. (c)	89. (d)	90. (d)
91. (b)	92. (b)	93. (b)	94. (a)	95. (a)	96. (c)	97. (d)	98. (d)	99. (a)	100. (a)

LEVEL 3

1. (a)	2. (b)	3. (a)	4. (a)	5. (a)	6. (b)	7. (d)	8. (a)	9. (c)	10. (b)
11. (b)	12. (c)	13. (a)	14. (c)	15. (b)	16. (d)	17. (d)	18. (c)	19. (d)	20. (c)
21. (c)	22. (d)	23. (b)	24. (d)	25. (b)	26. (c)	27. (c)	28. (d)	29. (c)	30. (d)
31. (c)	32. (b)	33. (d)	34. (c)	35. (d)	36. (b)	37. (c)	38. (a)	39. (a)	40. (b)
41. (a)	42. (b)	43. (a)	44. (a)	45. (d)	46. (c)	47. (d)	48. (a)	49. (b)	50. (b)

6

CHAPTER

ELECTRONIC MEASUREMENTS AND INSTRUMENTATION

6.1 MEASUREMENTS AND MEASUREMENT SYSTEMS

The measurements of a given quantity is essentially an act or the result of comparison between the quantity (whose magnitude is unknown) and a predefined standard.

6.2 UNITS, DIMENSIONS AND STANDARDS

The units for the fundamental dimensions are called fundamental or base units. In this set, the International System of Units, abbreviated SI, is used.

Metre (m)

Length equal to 1,650,763.73 wavelengths in vacuum corresponding to the $2p_{10} - 5d_5$ transition of krypton 86.

Kilogram (kg)

Equal to mass of international prototype kilogram, a hollow platinum-iridium mass having the same mass as 1 litre of water at 4°C preserved at Sèvres, France. This standard kilogram is the only artifact among the SI base units.

Second (s)

Equal to duration of 9,192,631,770 periods of radiation corresponding to the transition between two hyperfine levels of the ground state of cesium 133. The second was formerly defined as (1/86,400) part of a mean solar day.

Ampere (A)

Electric current which is flowing in two infinitely long parallel wires in vacuum separated by 1 metre produces a force of 200 nanonewtons per metre of length ($200 \text{ nNm}^{-1} = 2 \times 10^{-7} \text{ Nm}^{-1}$).

Kelvin (K)

Temperature equal to (1/273.16) of the triple point of water (or triple point of water equal 273.16 Kelvins).

Candela (cd)

Luminous intensity equal to that of (1/600,000) square metre of a perfect radiator at the temperature of freezing platinum.

The units for other dimensions are called secondary or derived units and are based on these fundamental units.

The three basic quantities are expressed dimensionally as L (length), M (mass) and T (time). All derived units can be dimensionally expressed in terms of the basic quantities, L, M, T, A, K, Cd from their defining formulae.

Rationalized MKSA System

S. No	Quantity	Sy.	Physical equation	Dimensions
1.	Current	I		$M^0 L^0 T^0 I^{-1}$
2.	Charge	Q	$Q = I t$	[TI]
3.	Emf	V	$V = \frac{\text{work done}}{\text{charge}}$	$[ML^2 T^{-2} I^{-1}]$
4.	Resistance	R	$E = IR$	$[ML^2 T^{-3} I^{-2}]$
5.	Flux magnetic	ϕ	$E = N d\phi/dt$	$[ML^2 T^{-2} I^{-1}]$
6.	Flux density	B	$B = \text{flux/area}$	$[MT^{-2} I^{-2}]$
7.	Mmf	$\mathcal{E}$	$\mathcal{E} = NI$	[I]
8.	Magnetizing force	H	$H = \frac{\text{mmf}}{\text{Length}}$	$[L^{-1} I]$
9.	Reluctance	R	$R = \mathcal{E}/\phi$	$[M^{-1} L^{-2} T^3 I^{-2}]$
10.	Inductance	L	$L = V dt/dI$	$[ML^2 T^{-2} I^{-2}]$
11.	Electric flux	ϕ	$\phi = Q$	[TI] = $ML^2 T^{-2} I^{-1}$
12.	Electric flux density	D	$D = \frac{\text{electric flux}}{\text{Area}}$	$[L^{-2} TI]$
13.	Electric field strength	E	$E = \text{potential gradient}$	$[MLT^{-3} I^{-1}]$
14.	Capacitance	C	$C = Q/E$	$[M^{-1} L^{-2} T^4 I^2]$

Deflection and Null Type Instruments

An instrument can be classified into two major categories:

1. Deflection Type

The deflection of the instrument provides a basis for determining the quantity under measurement.

- *PMMC* (Permanent magnet moving coil), the deflection of the moving coil is proportional to the current I , the quantity under measurement. (Electrical and electronics measurement and instrumentation)
- Torque $T_d = G \cdot I$
- Where G is a constant, depends on the flux density, number of turns and area of moving coil.
- Balancing effect is produced by a spring whose torque $T_c = K\theta$
where, K = spring constant.
- For balance condition

$$T_c = T_d; K \cdot \theta = G \cdot I$$

$$\theta = \frac{G \times I}{K}; I = \frac{K\theta}{G}$$

- The value of measured quantity, current I , depends upon the value of deflection and constant of the metre.

2. Null Type

In a null type of instrument, a zero or null indication leads to determination of the magnitude of measured quantity. Example is DC potentiometre

6.3 CHARACTERISTICS OF INSTRUMENTS AND MEASUREMENT SYSTEMS

Static Characteristics

The main static characteristics discussed here are:

Static Error

It is defined as the difference between the measured value and the true value of the quantity.

$$\delta A = A_m - A_t$$

where, δA = error

A_m = measured value of quantity

A_t = true value of quantity.

δA is also known as absolute static error of quantity A .

Relative static error ε_r is given by

$$\varepsilon_r = \frac{\text{Absolute error}}{\text{True value}} = \frac{\delta A}{A_t}$$

Static Correction

It is the difference between the true value and the measured value of the quantity.

$$\delta C = A_t - A_m$$

where, δC = static correction = $-\delta A$.

Reproducibility

It is the degree of closeness with which a given value may be repeatedly measured. Perfect reproducibility means that the instrument has no drift.

Drift

Drift means that with a given input, the measured value do vary with time. It is an undesirable quantity in industrial instrument, and cannot be easily compensated for.

Accuracy

It is the closeness with which an instrument reading approaches the true value of the quantity being measured.

It can be specified in terms of inaccuracy or limit of error.

Precision

It is a measure of the reproducibility of the measurement i.e., given a fixed value of a quantity, precisions, a measure of the degree of agreement within a group of measurement. The term 'precise' means clearly or sharply defined.

Dead Time

It is defined as the time required by a measurement system to begin to respond to a change in the measurement.

Dead Zone

It is defined as the largest change of input quantity for which there is no output of the instrument. For example, the input applied to the instrument may not be sufficient to overcome the friction so there is no output.

Resolution

If the input is slowly increased from some arbitrary input values, it will again be found that output does not change at all until a certain increment is exceeded. This increment is called resolution or discrimination of the instrument.

Loading Effect

The ideal situation in a measurement system is that when an element used for any purpose is introduced into the system, the original signal should remain undistorted. However, under practical conditions, it has been found that introduction of any element in a system results in distortion of original signal.

6.4 ERRORS IN MEASUREMENTS AND THEIR ANALYSIS

In most instruments, the accuracy is guaranteed to be within a certain percentage of full scale reading. Components are guaranteed to be within a certain percentage of the rated value. The limits of these deviations from the specified value are defined as limiting errors.

The magnitude of a quantity having a nominal value A_s and a maximum error or limiting error of $\pm \delta A$ must have a magnitude A_a between the limits $A_s - \delta A$ and $A_s + \delta A$ or
Actual value of quantity

$$A_a = A_s \pm \delta A$$

where, δA = limiting error, A_s = nominal value.

Relative Limiting Error

The relative (fractional) error is defined as the ratio of the error to the specified (nominal) magnitude of a quantity. Therefore,

$$\text{Relative limiting error } \varepsilon_r = \frac{\delta A}{A_s} = \frac{\varepsilon_a}{A_s}$$

$$\text{or } \varepsilon_0 = \delta A = \varepsilon_r A_s$$

$$\begin{aligned} \text{Relative limiting error, } \varepsilon_r &= \frac{A_a - A_s}{A_s} \\ &= \frac{\text{actual value} - \text{nominal value}}{\text{nominal value}} \end{aligned}$$

Combination of Quantities With Limiting Error

When two or more quantities each having a limiting error, are combined, it is advantageous to be able to compute the limiting error of the combination. The limiting error can be easily found by considering the relative increment of the function if the final result is in the form of an algebraic equation.

Sum of Two Quantities

Let y be the final result which is the sum of measured quantities u and v .

$$\therefore y = u + v$$

If the errors in the component quantities are represented by $\pm \delta u$ and $\pm \delta v$ then corresponding *limiting error* δy in y is given by

$$\frac{\delta y}{y} = \left(\frac{u}{y} \cdot \frac{\delta u}{u} + \frac{v}{y} \cdot \frac{\delta v}{v} \right)$$

Difference of Two Quantities

Let $y = u - v$

If the error in u , v are $\pm \delta u$ and $\pm \delta v$ respectively, the signs may be interpreted to give the worst possible discrepancy i.e., when the error in u is $+\delta u$, the error in v is $-\delta v$ and vice versa, then the corresponding relative limiting error δy in y is given by

$$\frac{\delta y}{y} = \pm \left(\frac{u}{y} \cdot \frac{\delta u}{u} + \frac{v}{y} \cdot \frac{\delta v}{v} \right)$$

Product of Two Quantities

$$X = x_1 \cdot x_2$$

$$\frac{\delta X}{X} = \pm \left(\frac{\delta x_1}{x_1} + \frac{\delta x_2}{x_2} \right)$$

Product or Quotient of More Than Two Quantities

Let $y = uvw$ or $y = [u/vw]$ or $y = [1/uvw]$

We have relative limiting error for y

$$\frac{\delta y}{y} = \pm \left(\frac{\delta u}{u} + \frac{\delta v}{v} + \frac{\delta w}{w} \right)$$

Relative limiting error of product of terms is equal to the sum of relative limiting errors of terms.

Quotient

$$X = [x_1/x_2]$$

$$\frac{\partial X}{X} = \pm \left(\frac{\delta x_1}{x_1} \mp \frac{\delta x_2}{x_2} \right)$$

Composite factor

Relative limiting error of y is

$$\frac{\delta y}{y} = \pm \left(n \frac{\delta u}{u} + m \frac{\delta v}{v} \right).$$

Type of Errors

No measurement can be made with perfect accuracy but it is important to find out what accuracy actually is and how different errors have entered into the measurement. A study of errors is a first step in finding ways to reduce them. Errors may arise from different sources are usually classified as under:

1. Gross Errors

This class of errors mainly covers human mistakes in reading instruments and recording and calculating measurement results.

2. Systematic Error

These type of errors are divided in to three categories:

Instrument Errors

These errors arise due to three main reasons:

- Due to inherent shortcomings in the instrument.
- Due to misuse of the instruments.
- Due to loading effects of instruments.

Environment Errors

These arises due to conditions external to the measuring device i.e., effect of temperature, pressure, humidity dust vibrations or external magnetic fields.

Observational Errors

There are many sources of observational errors. Errors on account of Parallax.

3. Random (Residual) Errors

The errors caused by disturbances, about which we are unaware are lumped together are called Random errors.

Statistical Treatment of Data Arithmetic Mean

The most probable value of measured variable (variant) is the arithmetic mean of the number of readings taken. The arithmetic mean is given by:

$$\bar{X} = \frac{x_1 + x_2 + x_3 + x_4 \dots x_n}{n} = \frac{\sum x}{n}$$

where, $\bar{X}$ = arithmetic mean

$x_1, x_2, \dots, x_n$ = readings or variants or samples

n = number of readings.

Dispersion

The property which denotes the extent to which the values are dispersed about the central value is termed as dispersion.

Deviation

Deviation is the departure of the observed reading from the arithmetic mean of the group of reading.

$$d_1 = x_1 - \bar{X}$$

$$d_2 = x_2 - \bar{X}$$

$$d_n = x_n - \bar{X}$$

Algebraic sum of deviation is

$$d_1 + d_2 + d_3 \dots + d_n$$

$$= (x_1 - \bar{X}) + (x_2 - \bar{X}) + (x_3 - \bar{X}) + \dots + (x_n - \bar{X})$$

$$= (x_1 + x_2 + x_3 \dots + x_n) - n\bar{X} = 0$$

$$\text{as } x_1 + x_2 + x_3 + \dots + x_n = n\bar{X}.$$

Algebraic sum of deviation is

$$= d_1 + d_2 + \dots + d_n = 0$$

Therefore, the algebraic sum of deviation is zero.

Average Deviation

The average deviation is an indication of the precision of the instruments used in making measurements.

Highly precise instruments yield a low average deviation between readings.

$$D = \frac{|d_1| + |d_2| + \dots + |d_n|}{n} = \frac{\sum |d|}{n}.$$

Standard Deviation (S.D)

Also known as *root mean square deviation*.

$$S \cdot D = \sigma = \sqrt{\frac{d_1^2 + d_2^2 + \dots + d_n^2}{n}} = \sqrt{\frac{\sum d^2}{n}}$$

In practice, the number of observations is finite:

When the number of observations is greater than 20, S.D is denoted by σ , while if the number is less than 20, the symbol used is (s).

The standard deviation of a finite number of data is given by

$$s = \sqrt{\frac{\sum d^2}{n-1}}.$$

Variance

It is known as *mean square deviation*.

$$V = (S.D)^2 = \frac{\sum d^2}{n} = \sigma^2.$$

6.5 CIRCUIT COMPONENTS (R, L, C)

Residues

It is not possible to have a circuit component which has only one property i.e., solely a pure resistance an inductance and capacitor, means, a resistor does not have resistance only but has an associated inductance and capacitance. The impurities in a circuit component produce unwanted quantities called residues.

6.6 ANALOG INSTRUMENTS

Analog Instrument

An analog device is the one in which the output is a continuous function of time and bears a constant relation to its input.

Classification of Analog Instruments

Indicating Instruments

They are those instruments which indicate the magnitude of quantity being measured. Ordinary voltmeters, ammetres and wattmeters belong to this category.

Recording Instruments

It gives a continuous record of the quantity beings measured over a specified period.

Integrating Instruments

It totalizes events over a specified period of time. Ampere hour and watt hour metre are examples of this category.

The analog instruments may also be classified on the basis of method used for comparing the unknown quantity with the unit of measurement:

1. Direct measuring instrument
2. Comparison instrument

Principle of Operations

Effect	Instruments
Magnetic effect	Ammetres, voltmeters, watt-metres, integrating metres
Heating effect	Ammetres and voltmeters

Effect	Instruments
Electrostatic effect	Voltmetres
Induction effect	A.C. ammetres, voltmeters, watt-metres, integrating metres
Hall effect	Flux metres, ammetres, and Poynting vector watt-metres

6.7 ELECTRO MECHANICAL INDICATING INSTRUMENTS

Operating Forces

Three types of forces are needed for the operation of any indicating instrument.

Deflecting Force

This force is required for moving the pointer from its zero position. The deflecting force can be produced by converting the electric current or potential into a mechanical force called deflecting force.

Controlling Force

This force is required in an indicating instrument in order that the current produces a deflection proportional to its magnitude.

Damping Force

It is necessary so that the moving system comes to its equilibrium position rapidly and smoothly without any oscillations.

Spring Control A hairspring attached to the moving system exerts a controlling torque.

The essential requirements for instatement springs are:

1. They should be non-magnetic.
2. They should be free from mechanical fatigue.
3. They should also have a low resistance temperature coefficient.

Damping System

The damping torque should be of such a magnitude that the pointer quickly comes to its final steady state position, without over shooting.

Galvanometres

A galvanometre is an instrument used for detecting presence of small current or voltage in a close circuit or for measuring their magnitude.

D'Arsonval Galvanometre

It is used for measurement of resistance and DC potentiometre work.

Ballistic Galvanometre

It is used for the measurement of quantity of electricity (charge) passed through it. The quantity of electricity passing through the galvanometre is proportional to the emf induced and hence to the change in flux linkage with each coil. *The galvanometre can therefore be calibrated to read the charge.*

6.8 ANALOG METRES

Type of Instruments

The main types of instrument used as ammeters and voltage are:

- **Permanent magnet moving coil (PMMC)** can be used for direct current measurement only.
- **Induction type** is used for alternating current only.
- The other type is used with either direct or alternating current.
- Moving iron and moving coil type both depend for their action upon the magnetic effect of current.
- **Electro-dynamometre** type of instruments are used both on AC as well as DC. They are also very useful as 'transfer instruments'.
- **Thermal instruments** have the advantage that their calibration is the same for both DC and AC. They are particularly suited for alternating current measurements. Since their deflection depends directly upon the heating effect of the alternating current, i.e., upon the rms value of the current. Their resistances are thus independent of the frequency or waveform of the current, and of any stray magnetic field which may exist in their vicinity.
- **Electrostatic instruments** have the advantage that their power consumption is very small, but it can only be used for large range of voltage measurement.
- **Induction type** is more generally used for watt-hour metres, than for ammeters and voltmeters owing to their comparatively high cost and inaccuracy of induction instruments.

Torque equation

Deflection torque is $T_d = NB IdI = GI$
where, $G = \text{a constant} = NB Id$

The spring control provides a restoring (controlling) torque $T_c = K\theta$

where, $K = \text{spring constant.}$

For final steady deflection $T_c = T_d$

Therefore, final steady deflection $\theta = [GI/K]$ or Current $I = K_i \cdot \theta$

where, $K_i = \frac{K}{G} = \text{a constant.}$

- Deflection is directly proportional to the average current (I_{av}) passing through the metre.
- Eddy Current damping

Ammetre Shunts

A DC ammeter is PMMC D'Arsonval galvanometre.

- Multiplying power

$$m = \frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}}$$

Resistance of shunt

$$R_{sh} = \frac{R_m}{(m-1)}$$

where, $I = \text{Current to be measured.}$

$I_m = I_{fs} = \text{full-scale deflection current of metre.}$

$R_m = \text{internal resistance of metre.}$

$R_{sh} = \text{resistance of the shunt.}$

Effect of Temperature Changes in Ammeters

The temperature error can be eliminated when the shunt and the moving coil are made of the same material.

Use of **swamping resistance of manganin** having resistance 20 to 30 times, the coil resistance is connected in series with the coil and a shunt.

Voltmetre Multipliers

Arsonval basic metre movement is converted into a voltmeter by connecting a series resistance with it.

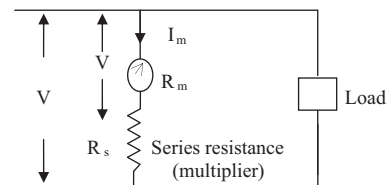


Fig. 6.1

$$V = I_m (R_m + R_s); \quad \frac{V}{I_m} = (R_m + R_s)$$

$$\frac{V}{I_m} - R_m = R_s; \quad R_s = \frac{V}{I_m} - R_m$$

where, R_s = multiplier resistance.

$I_{fs} = I_m$ = full scale deflection current of metre

R_m = internal resistance of metre

V = full range voltage of instrument.

Multiplying factor for multiplier

$$\frac{V}{v} = \frac{I_m (R_m + R_s)}{I_m R_m} = \left[1 + \frac{R_s}{R_m} \right]$$

$$M = \frac{V}{v} = \left(1 + \frac{R_s}{R_m} \right).$$

Resistance of multiplier $R_s = (m - 1) R_m$.

Errors in PMMC Instruments

- (a) Weakening of permanent magnets due to ageing and temperature effects.
- (b) Weakening of spring due to ageing and temperature effects.
- (c) Change of resistance of the moving coil with temperature.

Advantages PMMC instruments

1. The scale is uniform. (I_{av})
2. The power consumption is very low as $2.5 \mu\text{W}$ to $200 \mu\text{W}$.
3. The torque-weight ratio is high which gives a high accuracy.
4. A single instrument may be used for many different current and voltage ranges by using different values for shunts and multipliers.

Ohmmetres

It is a convenient direct reading device for measurement of resistance. It have low degree accuracy.

Megger

It is used for measuring high value of resistance, i.e., insulation resistance.

Moving Iron (MI) instruments

- At power frequencies, we are using moving iron instruments.

- Deflecting torque
 $T_d = [1/2] F [dL/d\theta]$

- Controlling torque
 $T_c = K\theta$

- Deflection

$$\theta = \frac{1}{2} \cdot \frac{I^2}{K} \frac{dL}{d\theta}$$

- Deflection is proportional to square of the r.m.s value of the operating current (I_{rms}).
- Air friction damping.
- For a liner scale product q , $[dL/dq]$ should be a constant.

Attraction Type

When the current flows through the coil, a magnetic field is produced and moving iron moves from the weaker field outside the coil to the strong field inside or the moving iron is attracted in.

Repulsion Type

In the repulsion types, there are two vanes inside the coil, one fixed and other movable. These are magnetized when the current flows through the coil and there is a force (or) (of) repulsion between the two vanes resulting in the movement of the moving vane.

Errors in Moving Iron Instruments

1. Errors with both DC and AC
 - (a) Hysteresis error
 - (b) Temperature error
 - (c) Stray magnetic field
2. Error with AC only

Frequency Errors

Changes in frequency may cause error due to changes of reactance of the working coil. The change of reactance of the instrument coil is important in case of voltmeter where an additional resistance R_s is used in series with instrument coil.

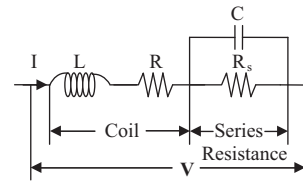


Fig. 6.2

Frequency error can be eliminated by using capacitor in parallel with series resistance R_s .

$$C = 0.41 \frac{L}{R_s}$$

Electrodynamics Type Instruments

A transfer instrument is the one that may be calibrated with a DC source and then used without modification to measure AC. This needs the same accuracy for both DC and AC.

Sinusoidal Currents

If currents i_1 and i_2 are sinusoidal and are displaced by a phase angle ϕ , i.e.,

$$i_1 = I_{m1} \sin \omega t \text{ and } i_2 = I_{m2} \sin (\omega t - \phi)$$

$$\text{Deflection } \theta = \frac{I_1 I_2}{K} \cos \phi \cdot \frac{dM}{d\theta}$$

It follows from the above that for sinusoidal alternating currents the deflecting torque and deflection are determined by the product of the rms values of the coil currents and cosine of the phase angle between them.

Electrostatic Instruments

In electrostatic instruments, the deflecting torque is produced by action of electric field on charged conductors.

$$T_d = \frac{\epsilon_0 r^2}{d} V^2$$

Electrodynamometre Ammetres

In this case, the fixed and moving coils are connected in series and, therefore, carry the same current i.e., $I_1 = I_2$ and $\phi = 0$.

$$\text{Therefore, Deflecting torque } T_d = I^2 \frac{dM}{d\theta}$$

$$\text{Therefore, Deflection } \theta = \frac{I^2}{K} \frac{dM}{d\theta}$$

Electrodynamometre Voltmetres

The electro-dynamometre movement is used as a voltmeter by connecting the fixed and moving coils in series with a high non-inductive resistance.

$$\text{Deflection torque } T_d = I_1 I_2 \cos \phi \frac{dM}{d\theta}$$

$$\text{Deflection } \theta = \frac{V^2}{KZ^2} \frac{dM}{d\theta}$$

Electrodynamometre type voltmeter is the most accurate type of AC voltmeter. But the sensitivities are low in comparison with the DC instruments and range from 10 to 30 Ω/V .

Hot Wire Instruments

The current to be measured is passed through a fine **platinum iridium wire**. On passage of current the wire gets heated and it expands. This expansion of wire causes the pointer to deflect.

Thermocouple Instrument

When two metals having different work function are placed together, a voltage is generated at the junction which is nearly proportional to the temperature. This junction is called a thermocouple temperature. This principle is used to convert heat energy to electrical energy at the junction of two conductors.

$$E = a(T_1 - T_2) + b(T_1 - T_2)^2 = a \Delta\theta + b(\Delta\theta)^2$$

where, a , b are constants whose value depends upon metals used.

$\Delta\theta$ = difference of temperature of hot and cold junction
 $= T_1 - T_2$.

Induction instruments

The working principle of induction instruments is similar to that of single phase induction motor. A torque is developed due to the interaction between two magnetic fields with a phase difference.

The deflecting torque is given by,

$$T_d \propto \frac{I^2 f}{Z}$$

Rectifier Instrument

Rectifier instruments are used for measurements of AC voltages. A rectifier element is used which converts the AC to a unidirectional DC and then using a PMMC metre the value of the rectified DC is measured. Rectifier instruments are highly sensitive with a very rugged construction.

6.9 MEASUREMENT OF ENERGY

Energy is the total power delivered or consumed over a time span.

Motor metres are a class of energy metre which measure the total energy in kilowatt hour (KWh) or the quantity of electricity in ampere-hour. Energy metres are integrating instruments. Motor metres are used for measurement of energy in both dc and ac circuit.

Metre constant is defined as the number of revolutions made per Kilo-Watt-hour (KWh).

The speed of the moving system is controlled by braking system. It is done with help of a permanent magnet.

Energy metres for ac circuit are generally induction type.

Energy is the total power delivered or consumed over a time interval.

$$\text{Energy} = \text{Power} \times \text{time}$$

$$W = \int_0^t vi \, dt.$$

Creep

In some metres, a slow but continuous rotation is obtained even when there is no current flowing though the current coil and only pressure coil is energized. This is called *creeping*.

Reason of Creeping

Due to over-compensation for friction. If the friction compensation device is adjusted to give a driving torque to compensate for static friction which is larger than the running friction, there is a tendency for the disc to run over when there is no current.

Excessive voltage across the potential coil.

Prevention of Creeping

In order to prevent creeping, two diametrically opposite holes are drilled in the disc.

Measurements of Power

Power is measured by wattmetre. Most of the wattmetres are electro-dynamometre type instruments. Dynamometre consists of two types of coils, one moving coil and two fixed coils. Here the fixed coils are connected in series with the load and carries the current in the circuit. So they are also called '**current coils**'. On the other hand, the moving coil carries current proportional to the voltage and it is called '**pressure coil**' or '**voltage coil**' is highly inductive.

In this type of wattmetres, **spring control is used** and the damping used is **air friction damping**. It is an indicating instrument.

The deflecting torque is given by

$$T_d = \frac{VI}{R_p} \cos \phi \frac{dM}{d\theta}$$

Control torque, $T_c = K\phi$

6.10 POWER FACTOR METRES

Measurement of Power Factor

Power factor measurement is done in the similar way as power is measured. These instruments also work mostly in electro-dynamic principle containing voltage and current coils.

But there are two moving coils instead of one along with two fixed coils. The two moving coils produces two deflecting torques.

$$T_{d1} \propto VI \cos \phi \sin \theta$$

$$T_{d2} \propto VI \sin \phi \sin \theta$$

$\theta \rightarrow$ angle of deflection

$\phi \rightarrow$ phase angle of the circuit

In equilibrium, $T_{d1} = T_{d2}$

$$\therefore \theta = \phi$$

Thus, deflection becomes equal to phase angle.

Power factor metres indicate directly, the power factor of the circuit to which they are connected. It is having:

- (i) Current circuit
- (ii) Pressure circuit

Current circuit It carries the current in the circuit whose power factor is to be measured.

Pressure circuit It is connected across the circuit whose power factor is to be measured.

6.11 MEASUREMENT OF RESISTANCE

1. Measurement of medium resistance:
 - (a) Ammetre-voltmetre-method
 - (b) Substitution method
 - (c) Wheatstone bridge method
 - (d) Ohmmetre method

2. Measurement of low resistance:
 - (a) Kelvin's double bridge method (KDB).
 - (b) Potentiometre method

Kelvin Double Bridge

It is one of the best available method for the precise measurement of low resistances. It is only a development of the Wheatstone Bridge by which the error due to contact and lead resistance are eliminated. The scheme of connections is as shown below:

X = unknown resistance

S = standard resistance of same order of magnitude as X

r = connecting link of low resistance to balance the error due to contact and lead

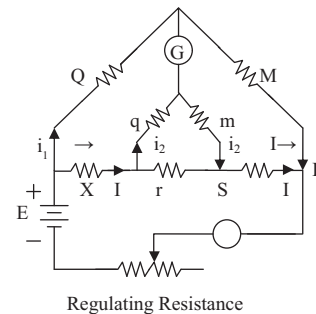


Fig. 6.3

Q, M and q, m are two pairs of known non-inductive resistance, and one pair out of Q, q or M, m is variable (for purposes of balancing the bridge).

Measurement of High Resistance

High resistance includes:

1. Insulation resistance of components
2. Resistance of high resistance circuit elements like in vacuum tube circuit
3. Leakage resistance of capacitors
4. Surface resistivity

Methods for Measurement of High Resistance

1. Direct deflection method
2. Loss of charge method
3. Megohm bridge
4. Megger

- **Loss of charge method:** In this method, the insulation resistance R to be measured is connected in parallel with a capacitor C and an electrostatic voltmeter. Capacitor is charge to some suitable voltage, by means of a battery having voltage V , and is then allowed to discharge through the resistance.

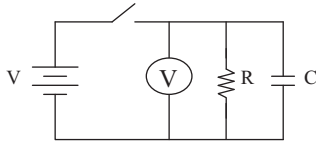


Fig. 6.4

- Voltage across capacitor at any instance t after the application of voltage is

$$V = V_o e^{(-t/RC)}$$

A.C. Bridges

- A.C. bridges are used for measurement of inductance, capacitance storage factor, loss factor.
- An A.C. bridge consists of four arms, a source of excitation and a balance detector.
- In A.C. bridge, each of the four arms is an impedance and the battery and the galvanometre of the Wheatstone bridge are replaced respectively by an a.c. source and a detector.
- Also used for measurement of phase shifting, providing feedback paths for oscillators and amplifiers, filtering out undesirable signal and measuring the frequency of audio signals.

Detectors: Commonly used for A.C. Bridges are

1. Head phone
2. Vibration galvanometres
3. Tunable
4. Amplifier
5. Detector.

General equation for bridge balance,

$$Z_1 Z_4 = Z_2 Z_3$$

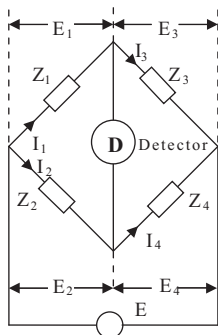


Fig. 6.5

Measurement of Self-Inductance

Maxwell's Inductance Bridge

This bridge circuit measures an inductance by comparison with a variable standard self-inductance.

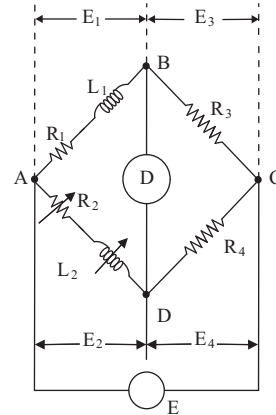


Fig. 6.6

R_3 and R_4 = Known and non-inductive resistance.

$$L_1 = \frac{R_3}{R_4} \cdot L_2.$$

Maxwell's Inductance-Capacitance Bridge

In this bridge, an inductance is measured by comparison with a standard variable capacitance.

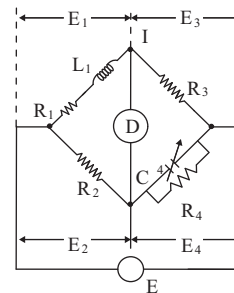


Fig. 6.7

$$R_1 = \frac{R_2 R_3}{R_4} \text{ and } L_1 = R_2 R_3 C_4.$$

It is suitable for low Q value.

Hay's Bridge

1. Used resistance in series, which uses a resistance in parallel with the capacitor.

Advantage

$$(i) L_1 = \frac{R_2 R_3 C_4}{1 + \omega^2 C_4^2 R_1^2}$$

gives simple expression for high Q coil.

$$(ii) \text{ Quality } Q = \frac{1}{\omega C_4 R_4}$$

- For high Q coil, R_4 should have small value. So it requires low value of resistor for R_4 whereas the Maxwell's bridge requires a parallel resistor, R_{4p} , of a very high value.

Disadvantage

Hay's bridge is suited for the measurement of high Q inductor, $Q > 10$, for low value of Q , $\frac{1}{Q^2}$ cannot be neglected and in that case use of Maxwell's bridge is more suited.

Measurement of Mutual Inductance

Heaviside Campbell Equal Ratio Bridge:

It is a modified and more updated version of Heaviside bridge used for mutual inductance measurement. Mutual inductance is measured in terms of self inductance.

Measurement of Capacitance

1. *De Sauty's bridge* is the simplest method of comparing two capacitances.

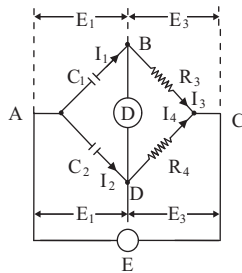


Fig. 6.8

$$C_1 = \frac{C_2 R_4}{R_3}$$

It is impossible to obtain balance if both the capacitors are not free from dielectric loss. So this is applicable only for lossless capacitor like air capacitor.

Shering Bridge

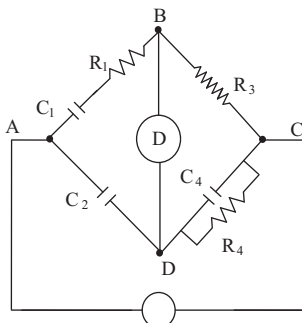


Fig. 6.9

$$\text{Loss factor } r_1 = \frac{R_3 C_4}{C_2} \quad \text{and} \quad C_1 = C_2 \left(\frac{R_4}{R_3} \right).$$

Dissipation factor/Dielectric loss $D_1 = WC_4 R_4$

- Used for measurement of the properties of insulators, capacitor bushings insulating oil and other insulating material.
- Suitable for small capacitances and usually supplied from a high frequency or a high voltage source.

Carey Foster Bridge

- (a) Used for measurement of capacitance in terms of a standard mutual inductance.
- (b) It can be used for measurement of mutual inductance in terms of a standard capacitance.

6.12 MEASUREMENT OF FREQUENCY

Wien's Bridge

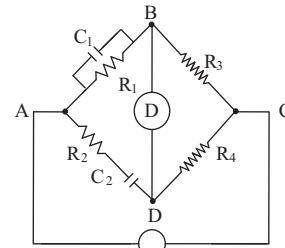


Fig 6.10

If $R_1 = R_2$ and $C_1 = C_2$

- $f = \frac{1}{2\pi RC}$.
- Measure frequency in AF and HF range.
- Measure capacitance
- Used in distortion Analyser as notch filter.

Wagner Earthing Device

For having accuracy in measurement, each component in a bridge has a defining screen connected to one end. This is made possible by the addition of a Wagner earth capacitance from the bridge network.

- Z_1, Z_2, Z_3 and Z_4 are the impedance of the bridge arms. Z_5 and Z_6 are the two variable impedances of the Wagner earth branches.
- Two impedances Z_5 and Z_6 must be capable of forming a balanced bridge with (Z_1 and Z_3) or (Z_2 and Z_4).
- C_1, C_2, C_3 and C_4 are stray earth capacitance.
- Putting switch in d position and adjusting Z_2 and Z_4 until minimum sound is obtain. Then putting switch to e and adjusting Z_5 and Z_6 to give minimum sound. Then again

connect switch to d to do same. The process is repeated until silence is obtained with the switch on d and one. Then all three points b , d and e are at earth potential.

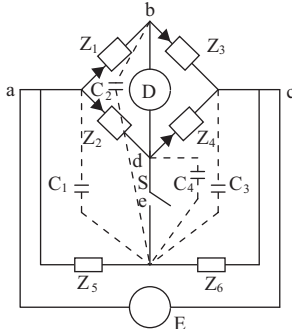


Fig. 6.11

6.13 ELECTRONIC MEASURING INSTRUMENTS

Electronic voltmeters use rectifiers, amplifier and other circuits to generate a current proportional to the voltage being measured. The current so produced is measured by a permanent magnet moving coil instrument (PMMC).

Advantages

1. High input impedance and low power consumption due to power supplied from auxiliary.
2. Detection of low level signal of the ($< 50 \mu A$, $< 50 \text{ mV}$) order of micro volt due to amplifying properties independent of frequency.
3. High frequency rangesome electronic voltmeter 10-100 MHz have range from dc to hundred of MHz suitable for rectifier.

Vacuum tube Voltmeter (VTVMs) may be considered as one of the todays most useful instruments for the measurement of ac and dc voltage.

Q-Metre

The determination of the storage factor Q is one of the most widely used means in the laboratory for testing radio frequency coils (RFC), inductors and capacitors. The storage factor is equal to $Q = \omega_o L/R$ where, ω_o is the resonant angular frequency, L is the inductance and R is the effective resistance of a coil. The effective resistance R , is never determined directly since its value depends upon the value of frequency. As it is well known, the value of effective resistance with AC differs from its DC value on account of skin effect and eddy current losses. Since the value of R varies in a complex manner with frequency, it is indirectly determined by measuring the value of Q .

The Q metre is an instrument which is designed to measure the value of Q directly and as such is very useful in measuring the characteristics of coils and capacitors.

The principle of working of this useful laboratory instrument is based upon the well-known characteristics of a resonant series R, L, C , circuit shown a coil of resistance R and inductance L in series with a capacitor C .

Measurement of Q

Correction for shunt resistance:

$$\text{Measured value, } Q_{\text{meas}} = \frac{\omega_o L}{R + R_{sh}}$$

$$\text{True value, } Q_{\text{true}} = \frac{\omega_o L}{R}$$

$$\therefore Q_{\text{true}} = Q_{\text{meas}} \left(1 + \frac{R_{sh}}{R} \right).$$

Thus, the measured value of Q is smaller than the true. Now if coils of high resistance (low Q coil) are being measured, the difference between the two may be negligible. But when measurements are done on low resistance (high Q) coils, the error caused on this account may be serious.

Correction for Distributed Capacitance

The distributed capacitance or self-capacitance of measuring circuit modifies the true value of Q . The measured value of Q is less than the true value by a factor that upon the value of the distributed (self) capacitance and the tuning capacitor. It can be shown that

$$\therefore Q_{\text{true}} = Q_{\text{meas}} \left(1 + \frac{C_d}{C} \right)$$

C_d = distributed or self-capacitance and

C = tuning capacitance.

Measurement of Inductance

The value of inductance is given by

$$L = \frac{1}{4\pi^2 f_o^2 C}$$

The value f_o and C are known and therefore the value of inductance may be calculated.

Measurement of Effective Resistance

The value of the effective resistance may be computed from the

$$\text{relation } R = \frac{\omega_o L}{Q_{\text{true}}}.$$

Measurement of Self Capacitance

The self-capacitance is measured by making two measurement at different frequencies. The capacitor is set to a high value, and

the circuit is resonated by adjustment of the oscillator frequency. The resonance is indicated by the circuit Q metre. Let the values of tuning capacitor be C_1 and that of frequency be f_1 under these conditions. Therefore,

$$f_1 = \frac{1}{2\pi\sqrt{L(C_1 + C_d)}}$$

The frequency is now increased to twice its initial value and the circuit is resonated again this time with the help of tuning capacitor. Let the value of tuning capacitor C_2 and that of frequency be f_2 under these conditions, Thus,

$$f_2 = \frac{1}{2\pi\sqrt{L(C_2 + C_d)}}$$

Now $f_2 = 2f_1$

$$\therefore \frac{1}{2\pi\sqrt{L(C_1 + C_d)}} = 2 \times \frac{1}{2\pi\sqrt{L(C_2 + C_d)}}$$

or distributed capacitance, $C_d = \frac{C_1 - 4C_2}{3}$.

Measurement of Bandwidth

The measurement of bandwidth with a Q metre is similar to the one used for measurement of effective resistance by variation of frequency.

Measurement of Capacitance

For measurement of capacitance, a dummy coil is connected across terminal T_1 and T_2 . The circuit is resonated by varying the value of the tuning capacitor. Let this value be C_1 .

This capacitor under test C_T is now connected across terminals T_3 and T_4 . This puts the test capacitor in parallel which tuning capacitor. The circuit is resonated again by varying the value of tuning capacitor. Let this value be C_2 . Therefore value of capacitance under test is $C_T = C_1 - C_2$.

6.14 CATHODE RAY OSCILLOSCOPE (CRO)

- It is a very useful and versatile laboratory instrument used for display, measurement and analysis of waveforms.
- Normal form of a CRO uses a horizontal input voltage, which is an internally generated ramp voltage, called '*time base*'. This moves the luminous spot periodically in a horizontal direction from left to right over screen.
- Vertical input to the CRO is the voltage under investigation. This moves luminous spot up and down with current value of the voltage.
- CRO operates on voltage. But it is possible to convert current, strain, acceleration, and pressure into voltage with the help of transducers.

- Used to investigate waveforms, transient phenomena, for very low frequency range to the radio frequencies.
- *Electron gun* assembly produces a sharp focused beam of electron, which are accelerated to high velocity. This focused beam strikes the fluorescent screen with sufficient energy.
- *Deflection plate* assembly moves beam vertically up and down and the voltage applied to the other pair of plates move the beam horizontally from one side to another.
- *Screens*: made up of phosphorescence material like phosphors.

Aquadag

The bombarding electrons striking the screen, releases secondary emission electron. These are collected by an aqueous solution of Graphite called 'Aquadag'. The collection of secondary electron is necessary to keep the CRT in a state of electrical equilibrium.

- Short persistence phosphors require more frequent refreshes whereas long persistence phosphors may result in character fading slowly, giving a trace after glow or trails.
- Short persistence phosphors (P_1, P_2, P_{11}, P_{31}), long persistence phosphors (P_{19}, P_{26}, P_{33}).

Measurement of Phase and Frequency (Lissajous Patterns)

Consider the characteristics of patterns that appear on the screen of a CRT when sinusoidal voltages are simultaneously applied to horizontal and vertical plates. These patterns are called 'Lissajous Patterns'.

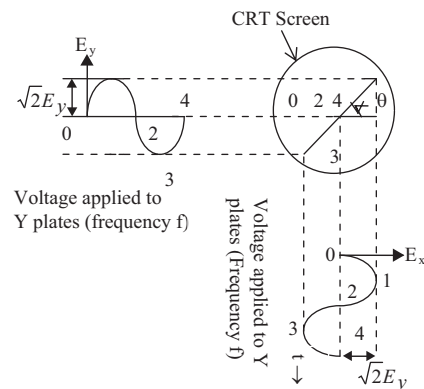


Fig. 6.12 Lissajous pattern with equal frequency voltages and zero phase shift

When two sinusoidal voltages of equal frequency which are in phase with each other are applied to the horizontal and vertical deflection plates, the pattern appearing on the screen is a straight line.

When two equal voltages of equal frequency but with a phase shift ϕ (not equal to 0° or 90°) are applied to a CRO, we obtain an ellipse. An ellipse is also obtained when unequal voltage of same frequency are applied to the CRO.

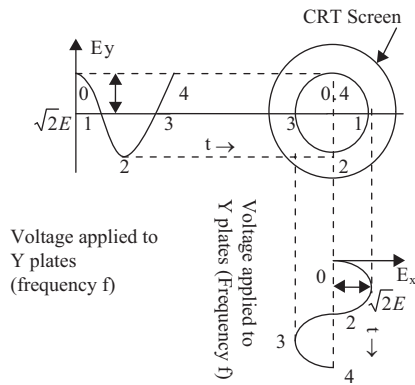


Fig. 6.13 Lissajous pattern with equal voltages of equal frequency and a phase shift of 90°

Frequency Measurements

The two waves start at the same instant. Lissajous pattern may be constructed in the usual way and a eight shaped pattern with two loops is obtained. If the two waves do not start at the same instant, we get different patterns for the same frequency ratio. The Lissajous patterns for other frequency ratios can be similarly drawn.

$$\frac{f_y}{f_x} = \frac{\text{number of times tangent touches top or bottom}}{\text{number of times tangent touches either side}}$$

$$= \frac{\text{number of horizontal tangencies}}{\text{number of vertical tangencies}}$$

f_y = frequency of signal applied to Y plates

f_x = frequency of signal applied to X plates

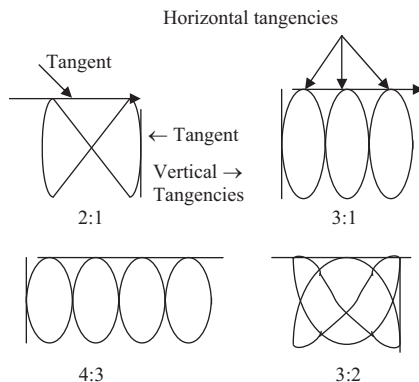


Fig. 6.14 Lissajous patterns with different frequency ratios size

The above rule, however, does not hold for the Lissajous patterns with free ends. The simple rule mentioned above needs following modifications.

6.15 SPECTRUM ANALYSER

In a spectrum analyser, we obtain a visual display on a CRT at one instant a range or sweep of frequencies. The variation on range is done electronically at a rapid rate. (This method is distinct from the discrete method. In the discrete method of the frequency response, an amplifier is to be checked, from 50 Hz to 15 kHz, spot frequencies from an audio oscillator at 50 Hz, 100 Hz, 400 Hz, 1 k, 5 k, 10 k and 15 k. Constant levels are fed to the amplifier and its output is measured on a voltmeter probably calibrated in dB or dBm frequency after frequency. This is a time consuming process).

The spectrum analyser is similar to converting super-heterodyne receiver. This is a block diagram of an analyser.

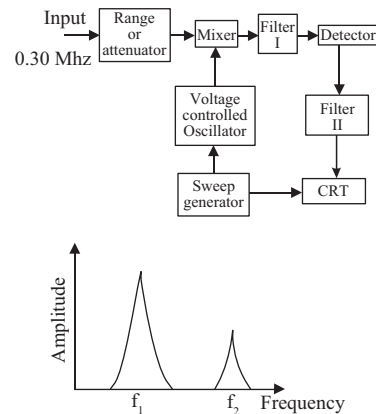


Fig. 6.15

If we want a display in time domain i.e., time vs amplitude, an ADC–Memory–DAC circuit is introduced before the mixer.

The range of frequency swept by the analyser is called the *dispersion* of the spectrum analyser. The first local oscillator has a frequency range of less than an octave.

Spectrum Analyser Application

1. Signal purity
2. Modulation

Distortion Analyser

An amplifier to which a pure sine wave is fed, may have at its output signals other than the fundamental though the magnitude may be at much lower intensity. This is because of the non-linearity of components like valves and transistors. The output voltage can be stated as

$$V_o = K_o + K_1 V_{in} + K_2 V_{in}^2 + K_3 V_{in}^3 + \dots$$

The first two terms are linear but the third term and above are of higher degree. Taking the 3rd term for a sine wave, the output is

$$K_2 V_{in}^2 = K_2 (A \sin \omega t)^2 = \frac{K_2 A^2}{2} (1 - \cos 2\omega t).$$

We see that the output contains a 2nd harmonic of the input frequency at half the amplitude. So the presence of frequencies other than the fundamental or the desired frequency is called distortion.

The distortion analyser mainly consists of a Wein circuit which tunes out the input frequency to the circuit. What remains are the spurious frequencies whose voltage is measured on a thermocouple or square law voltmeter calibrated in percentage. This measurement is called THD, total harmonic distortion.

$$\text{THD} = \sqrt{D_2^2 + D_3^2 + D_4^2 + \dots D_n^2}$$

$$\text{where, } D_2 = \frac{A_2}{A_1}, D_3 = \frac{A_3}{A_1} \dots D_n = \frac{A_n}{A_1}$$

where, A_2, A_3 etc., are the effective magnitudes of 2nd, 3rd harmonic frequencies and A_1 the effective magnitude of the fundamental.

The bridged- T filters out the fundamental with the switch S in position A , the metre indication being minimum. Switch S is thrown to position B and attenuator adjusted to give the same output as in A . The attenuator reading is the rms distortion in % or db below the fundamental.

Wave Analyzer

It is designed to measure relative amplitudes of single frequency components in a complex waveform. It acts as a frequency selective voltmeter which is tuned to the frequency of one signal while rejecting the other signal components.

AC Potentiometre

1. A necessary requirement for balancer in an ac potentiometre is the equality of voltages being compared at all instants. This requires equal phase and magnitude at all instants.
2. A vibration galvanometer which is a tuned device, is usually used as a detector in ac potentiometre.

6.16 RECORDERS

Potentiometric Recorders

The basic disadvantage of a galvanometer type of recorder is that it has a low input impedance and a limited sensitivity. A simple method of overcoming the input impedance problem is to use an amplifier between the input terminals and the display or indicating instrument. However, this technique, while producing a high input impedance (so as to reduce loading effects) and improved sensitivity, results in an instrument having low accuracy.

6.17 INSTRUMENT TRANSFORMERS

Transformer used in conjunction with measuring instruments for measurement purpose are called "Instrument Transformers". The transformer used for measurement of current is called "current transformer" or "CT" and transformers used for voltage measurement are called "potential transformers" or simply "P.T".

These are used for the measurement of current, voltage, power and energy.

The advantages of using instrument transformer along with measuring instruments are:

1. They increase the range of measuring instruments. A 5A ammeter may be used to measure 1000 A with the help of a 1000/5A ratio current transformer.
2. They isolate the measuring circuit with the power circuit, thereby minimizing any personal hazards of an operator.
3. Accuracy of measurement increases.
4. Power consumption is low.
5. Several instruments are operated from a single transformer.

Burden

Voltmeter, ammeters, wattmeter or any such measuring instruments, connected to the secondary winding of an instrument transformer is called burden. It is expressed in volt ampere ratings at rated secondary current or voltage at some particular power factor.

Current Transformers

They are operated in short circuit condition. The current in the secondary of a C.T. is decided by the primary current and not by the impedance of secondary circuit.

Potential Transformer

Potential transformers are used to operate voltmeters, the potential coils of wattmeters and relays from high voltage lines. The primary winding of the transformer is connected across the line carrying the voltage to be measured and the voltage circuit is connected across the secondary winding. Its design is similar to power transformer. The secondary winding is designed so that a voltage of 100 to 120 V is delivered to the instrument load.

Advantage of Transformers

- (a) When instruments are used with instrument transformer, their readings do not depend upon their constant viz., R , L and C as is the case with shunts and multipliers.
- (b) Very cheap moderate rating instruments may be used to measure large currents and high voltages. A 5 A ammeter may be used to measure 1000 A with the help of a 100.00/5

A ratio current transformer or a 110 voltmetre may be used to measure a voltage 60 kV with the help of 66000/110 V ratio potential transformer.

- (c) Great reduction in the cost of transformer and instruments.
- (d) The measuring circuit is isolated from the power circuit which is of great importance in high voltage systems.
- (e) There is a low power consumption in measuring circuit.
- (f) Several instruments can be operated from a single instrument transformer.

Minimizing Errors in Potential Transformer

- (a) Magnetising and loss components
- (b) Resistance and leakage reactance
- (c) Turns compensation

Comparison of Current and Potential Transformer

The potential transformer may be considered as a parallel transformer with its secondary nearly under open circuit conditions whereas the current transformer may be thought as series transformer under virtual short circuit conditions. Thus, the secondary of a potential transformer can be open-circuited without any damage being caused either to the operator or to the transformer.

6.18 A/D AND D/A CONVERTER, DIGITAL VOLTMETRE

An analog, derived from the word analogy, is a continuously variable system. An analog system is a proportional system where, we obtain signals proportional to the quantity being measured such as temperature, pressure, velocity or electrical quantities like voltage, current. In analog metres, there is a deflection of the pointer proportional to the quantity being measured. The deflection is a percentage of the full scale deflection.

Digital Instruments

Advantages

- No reading errors.
- High resolution.
- Transfer and processing of digital signals without loss of accuracy.

A digital voltmeter (DVM) converts the analog voltage into a BCD (Binary Coded Decimal) form which is then decoded and displayed on some form of read out such as seven segment decoder.

An analog to digital or digital to analog system consist of the following states. The physical variable is converted by a transducer into an equivalent electrical signal. This analog output

is converted into pure binary or BCD by an A/D converter and stored in a digital computer. This stored program is converted to an analog to signal by a D/A converter. Sometimes this analog output besides display may be used for controlling the physical variable.

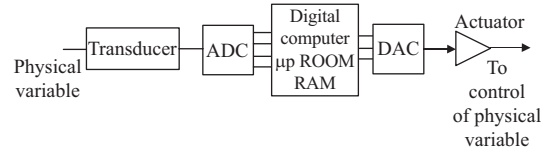
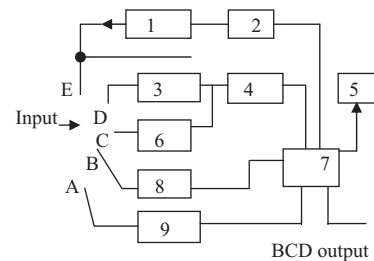


Fig. 6.16

A digital voltmeter (DVM) displays the value of AC or DC voltages being measured directly as discrete numerical in the decimal number system. These voltmeters have the following advantages:

Digital Multimetre

With the additional capability to measure AC/DC voltage and current, and resistance, the digital multimetre (DMM) offers increased versatility. In the A.C. voltage mode, the applied input is fed through a calibrated, compensated attenuator, to a precision full-wave rectifier circuit followed by a ripple-reduction filter. The resulting DC is fed to ADC and the subsequent display system.



A → DC voltage; B → DC current; C → AC current D → AC voltage; E → resistance

Fig. 6.17 Block diagram of a Digital Multimetre

Block Name

1. Current source
2. Buffer AMP
3. Calibrated attenuator
4. Precision AC/DC converter
5. Display
6. Shunt
7. A/D converter
8. Shunt
9. Calibrated attenuator

For current measurements, the drop across an internal calibrated shunt is measured, directly by the ADC in the DC conversion in the AC current mode. This drop is often in the range of 200 mV. Due to the lack of precision in the AC-DC conversion, the accuracy in the AC range is in general of the order of 0.2 to 0.5%. In addition, the measurement range is often limited to about 50 Hz at lower frequency end due to the ripple in the rectified signal becoming a non-negligible percentage of the display and hence resulting in fluctuation of the displayed number. At the higher frequency end, deterioration of the performance of the AC/DC converter limits the accuracy. The AC measurement range is often average reading, RMS calibrated.

In the resistance range, the DMM operates by measuring the voltage across the externally connected resistance, resulting from a current forced through it from a calibrated internal current source. The accuracy and stability of the resistance measurement is of the order of 0.1 to 0.5% depending on the accuracy and stability of the internal current sources. The accuracy may be poorer in the highest range, which is often about 10 to 20 M Ω . In the lowest range, the full scale may $\approx$ 200 ohms with a resolution of about 0.01 ohms for a 4(1/2) digit DMM. The effect of the lead resistance will have to be carefully considered in this range of resistance measurement.

6.19 TRANSDUCERS AND THEIR APPLICATIONS

A general arrangement of most measuring systems consists of three stages:

1. An input device to sense the measured i.e., sensor detector to give proportional output.
2. A signal processor or conditioner. This may consist of amplification, filtering unwanted signals and making it suitable for the recording device.
3. An output for read out.

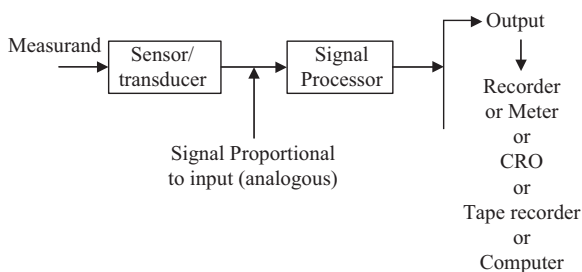


Fig. 6.18

Here, we are concerned with the first stage of conversion of a particular physical quantity equivalent electrical signals. This type of device is known as **transducer**.

There are two type of transducers (1) passive or modulating type and (2) self generating.

6.20 MEASUREMENT OF DISPLACEMENT

Application of force to a medium causes displacement for example, in a piston or dash pot assembly. Force is through variable and displacement across. In the this case, there are two transducers, one the primary transducer for converting the force into displacement and the second, the displacement causing the variation of an electrical element or voltage/current.

The primary transducer are diaphragm, flat or conjugated, bellows, tube, straight tube, mass cantilever and pivot torque.

The electrical signal is caused by the displacement due to variations in resistance, capacitance, inductance, differential transformer, ionization, oscillation, piezoelectricity, photo electricity.

Resistance Transducers

As per the fundamental equation for resistance

$$R = \rho \frac{L}{A}$$

Variation of any one of ρ , L or A causes a change in resistance.

Change of L may be caused in a potentiometre through which a steady current passes. Change of resistance creates a voltage change which can be read on a metre calibrated in length (displacement). Potentiometres are called pots and it can be either linear or circular.

Resistance Strain Gauge

A more important device in the measurement of displacement is the Strain Gauge in which all the three variables ρ , L , A are simultaneously affected by the input strain.

There are three types of resistance strain gauges:

1. Metallic resistance strain gauge made of metallic wires such as constantan (Cu-Ni alloy) Nichrome *V* or platinum alloy.
2. Foil strain gauge consists of a thin, 8 to 15 μm nitro-cellulose impregnated paper on which is photo etched metal alloy filaments as resistance material. **For higher temperature, an epoxy backing is used instead of paper.** The active length of the gauge is along the transverse axis. The gauge should be mounted with its transverse axis in the same direction as the direction of application of force or strain. Thus, elongation of the gauge by force (tension) increases by resistance and compressing the gauge reduces the length and consequently the resistance.

6.21 MEASUREMENT OF PRESSURE

Pressure is defined as the amount of force applied to a surface or distributed over it and is measured as force per unit area.

Methods of Pressure Measurement

Most pressure instruments measure a difference between two pressures one usually being that of the atmosphere.

The different methods of pressure measurement are listed below:

Manometres

The manometre is the simplest measuring instrument used for gauge pressure (low-range pressure) measurement.

The action of all manometres depends on the effect of pressure exerted by a fluid at a depth.

The Barometre

Since manometres inherently measure the pressure difference between the two ends of the liquid column, if one end is at zero absolute pressure, then the difference in height of the liquid from the zero reference indicates the absolute pressure. This is the principle of the barometre.

The C-Type Bourdon Tube Pressure Gauge

The Bourdon tube is the most frequency used pressure gauge because of its simplicity and rugged construction. It covers range from 0.15 psig to 0100,000 psig, as well as vacuum from 0 to 30 inches of mercury.

Diaphragm Pressure Transducers

Diaphragms are widely used for pressure (gauge pressure) and draft measurements particularly in very low ranges. They can detect a pressure differential even in the range of 0 to 4 mm.

The diaphragms can be in the form of flat corrugated or dished plates and the choice depends on the strength and amount of deflection desired. In high precision instruments, the diaphragms are generally used in a pair, back to back, to form an elastic capsule.

Bellows

The bellows-type gauges are used for the measurement of absolute pressures (normal as well as low pressure). It is somewhat more sensitive than Bourdon tube gauges. It is generally used for the range down to 155.1 mm Hg (3 psi). It may be used for even lower pressures up to 40mm Hg by making the bellows large enough. The bellows are made of an alloy which is ductile, has strength and retains its properties over long use, i.e., has very little hysteresis effect. They are used in two forms, in one arrangement, pressure is applied to one side of the bellows and the resulting deflection is counter balanced by a spring. This arrangement indicates the gauge pressure.

In another differential arrangement, the differential pressure is also indicated. In this device, one pressure is applied to the inside of one sealed bellows, while the other pressure is applied to the inside of another.

Measurement of Vacuum

Vacuum pressures are those which are below atmospheric. With modern vacuum pressure systems, it is possible to obtain pressures from 1000 m bar (approximately 1 atmosphere) down to 10m bar. There is no single transducer available which covers this full range. Down to 1 m bar, it is possible to use some of the techniques, e.g., manometres and diaphragm type transducers. Some of the methods of vacuum measurement are discussed below:

Capsule Gauges

Capsules are more sensitive than bellows and bourdon tubes. They are used for low pressure measurements and where highest accuracy is required.

Pirani Gauge

It consists of two wire filament only filament serves as a reference and is sealed in an evacuated glass.

Electrical Pressure Transducers

“A transducer is a device which converts one form of energy into another form of energy”. However, in the field of electrical instrumentation “a transducer is defined as a device which converts a physical quantity, a physical condition, or mechanical output into an electrical signal, a physical condition or mechanical output into an electrical signal.”

Strain Gauge Pressure Transducer

Strain gauge is a passive type resistance pressure transducer whose electrical resistance changes when it is stretched or compressed. It can be attached to a pressure sensing diaphragm.

Basic Principle

The strain gauge is a fine wire which changes its resistance when mechanically strained, due to physical effects. A strain gauge may be attached to the diaphragm so that when the diaphragm flexes due to the process pressure applied on it, the strain gauge stretches or compresses. This deformation of the strain gauge causes the variation in its length and cross-sectional area due to which its resistance also changes.

The resistance change of a strain gauge is usually converted into voltage by connecting one, two, or four similar gauge, as of a Wheatstone bridge (known as strain gauge bridge), and applying excitation to the bridge. The bridge output voltage is then a measure of the pressure sensed by the strain gauges.

Capacitive Pressure Transducers

The principle of operation of capacitive pressure transducers is based upon the familiar capacitance equation of the parallel plate capacitor, i.e.,

$$C = \frac{\epsilon_0 \epsilon_r A}{d} \text{ farad} \quad (5.4)$$

Servo Pressure Transducers

A servo pressure transducer is also called a “force balance pressure transducer”. It produces an electrical signal proportional to the pressure. Transducer is used in many industrial differential pressure cells.

Pressure Switches

A pressure switch turns an electric circuit ‘ON or ‘OFF’ at a preset pressure. This pressure is called the set point of the switch. A pressure switch is used in some form of control e.g., to operate a solenoid valve a given pressure or start up a pump.

The pressure switch is usually a micro switch or a mercury switch, A Bourdon tube, a diaphragm or a bellows can be used to actuate the switch.

Inferential Flow Measurements

In the inferential type of flow measuring methods, the flow rate is inferred from a characteristic effect of a related phenomenon: A classic example of an inferential measurement is a human body running fever, resulting from a serious sickness or disability, in which the rise in body temperature (fever) is not the cause of sickness but a characteristic phenomenon resulting from the ailment.

The following are the inferential type of flow measuring methods:

Reynolds Number

Reynolds number is a very important reference number in the accurate determination of flow. It is used to determine the point at which the flow goes from the viscous to the turbulent stage, as the flow changes from viscous to turbulent and vice versa. There is a very little change in the value of the flow coefficient, but there is accuracy desired when head metres are employed, then corrections will have to be made for the Reynolds numbers. It was discovered by Osborne Reynolds in the late 1800s and was named in his honour. Reynolds number is given by the equation,

$$R_D = \frac{VD\rho}{\mu}$$

Orifice Plates

Orifice plates, are the simplest and cheapest form of primary elements and are used more frequently than all other types. An orifice plate is inserted in the line and the differential pressure across it, is measured. There are four types of orifice plates which are listed below:

Ventured Tubes

A venturi tube is used where permanent pressure loss is of prime importance, and where maximum accuracy is desired in the measurement of high viscous fluids.

Flow Nozzles

The flow nozzles are used for flow measurement at high fluid velocities and are more rugged and more.

Rugged and more resistant to erosion than the sharp edged orifice plate.

Variable Area Flowmetres

In the variable area flowmetres, the size of the restriction is adjusted by an amount necessary to keep the pressure differential constant, when the flow rate changes and the amount of adjustment required proportional to the flow rate.

Rotametes

The rotametre is the most extensively used form of the variable area flowmetre. It consists of a vertical tapered tube with a float which is free to move up or down within the tube.

Turbine Flowmetres

The turbine flowmetre is used for the measurement of liquid, gas and very low rates. It works on basic principle of turbine. It consists of a multi-bladed rotor (turbine wheel) which is mounted at right angles to the axis of the flowing liquid.

Thermal Flowmetres

Thermal flowmetres are very popular for the measure flow rate in terms of mass, which is a very desirable feature, specially on gas service. There are two types of thermal flowmetres.

Ultrasonic Flowmetres

In ultrasonic flowmetres, the measurement of flow rate is determined by the variation in parameters of ultrasonic oscillations. There are two types of ultrasonic currently in use:

1. Time difference type
2. Doppler flowmetres.

Temperature Measurements

$$\frac{^{\circ}\text{C}}{1000} = \frac{^{\circ}\text{F} - 32}{180} \quad (1)$$

$$^{\circ}\text{K} = ^{\circ}\text{C} + 273.15 \quad (2)$$

The Rankine scale is abbreviated as $^{\circ}\text{R}$. On the Rankine scale, the ice-point is 491.7°R and the steam point is 671.7°R .

Temperature in Fahrenheit ($^{\circ}\text{F}$) can be converted into Rankine ($^{\circ}\text{R}$) by using the equation:

$$^{\circ}\text{R} = ^{\circ}\text{F} + 459.69$$

Both the Rankine and Kelvin temperature scales are called *absolute scales* because they use absolute zero as one of their reference points.

Methods of Temperature Measurement

The temperature measuring instruments are classified according to the nature of the change produced in the testing body by the change of temperature. They may be classified as follows:

Filled System Thermometers

The basic components of a filled system thermometer consists of a Bourdon tube, a capillary tube, and a thermometer bulb all interconnected as shown. The entire system is sealed after filling with.

An appropriate liquid (known as filling-liquid) at a pressure at the normal ambient temperature. The common liquids that are used are mercury, ethyl alcohol ethylene and toluene. When in use, the thermometer bulb is installed inside the substance to be measured. This causes the filling liquid inside the bulb to heat or cool until its temperature matches the temperature of the measured substance. This change in temperature causes the filling liquid to expand or contract and thus, the Bourdon tube moves. With the increase in temperature (heating), the liquid expands and this expansion forces the Bourdon tube to uncoil. With the decrease in temperature (cooling), the liquid contracts and it forces the Bourdon tube to coil more tightly. The movement of the Bourdon tube may be used to drive a pointer for indicating temperature or to drive the pen on a strip chart.

Basically, there are four types of filled system thermometers:

Resistance Thermometer

The resistance of certain metals changes with temperature change. Resistance thermometer utilizes this characteristics, with the increase of temperature, the electrical resistance of certain metals increases in direct proportion to the rise of temperature. Therefore, if the electrical resistance of a wire is known and calibrated material is measured, the temperature of the wire can be determined. Platinum, copper and nickel are generally

used in resistance thermometers. In this type of thermometer, a temperature sensitive resistance element is fabricated in a suitable form to insert in medium whose temperature is to be measured, and is connected by leads to a wheat stone bridge.

Metals Thermocouples

The working principle of a thermocouple depends on the thermo-electric effect. If two dissimilar metals are joined together so as to form a closed circuit, there will be two junctions, where they meet each other. If one of these junctions is heated, then, a current flows in the circuit which can be detected by a galvanometer. The amount of the current produced depends on the difference in temperature between the two junctions and on the characteristics of the two metals. This was first observed by Seebeck in 1821 and is known as Seebeck effect.

Thermistors

Thermistors are semiconductors, made from a specific mixture of pure oxides of nickel, manganese, copper, cobalt, iron, magnesium titanium, and other metals sintered at temperatures above 982°C . Their distinguishing characteristics are a **high temperature coefficient, usually negative**, although it can be positive as well and the fact that their resistance is a function of absolute temperature.

Pyrometres

Pyrometres is a technique for measuring temperature without physical contact. It depends upon the relationship between the temperature of a hot body and the electromagnetic radiation emitted by the body. When a body is heated, it emits thermal energy known as heat radiation. A black matt surface (or a black body) is a very good absorber of heat radiations and, also a very good emitter of such radiations when heated. Pyrometry is a technique for determining a body's temperature by measuring its electromagnetic radiation.

1. Radiation pyrometres
2. Optical pyrometres

Radiation Pyrometres

Operation of radiation pyrometer is based upon the measurement of radiant energy emitted by the hot body.

Optical Pyrometres

Optical pyrometres provide an accurate method of measuring temperatures between 600°C and 3000°C and are very useful for checking and calibrating radiation pyrometres. But they are not suitable for recording or controlling temperatures.

6.22 DATA ACQUISITION SYSTEMS

Telemetry means remote monitoring of functional parameter to maintain the health of the system.

Telemetry is Resorted to on Account of

- Hazards may be to the operating personnel as well as the indicating instruments. Such places are nuclear reactors due to radiation, chemical processor on account of explosive, toxic and pyrometric nature, high voltages such as generators and transmitters of high power.
- Inaccessibility—The physical location of the parameters may be inaccessible as for instance satellites and human bodies while taking ECG etc.

Transfer of data from the point of location to the point of observation and recording is done by cable pairs or by wireless or by a combination of both. This is known as telemetry.

There are two types of data acquisition systems, analog and digital.

Analog systems have wide bandwidths but lower accuracy.

Digital systems are slowly varying and hence narrow bandwidth but have high accuracy and low per channel cost.

Analog Data Acquisition System

A block diagram of ADAS is given. There are two types. Either data may be collected from n source and multiplexed into one channel by A/D multiplex or the collected data from a source are passed through an A/D converter and fed into one channel by digital multiplexer.

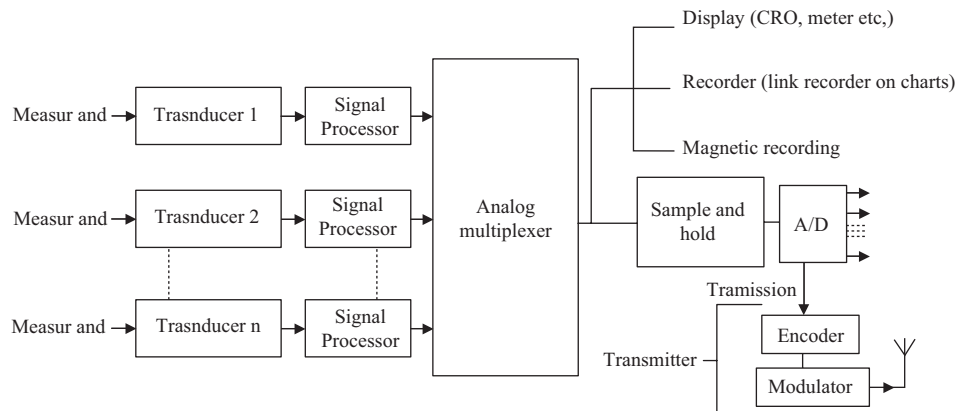


Fig. 6.19

Transducer

It converts electrical and non-electrical quantities into electrical signals.

Signal processing

Signals are of very low strength and they are amplified by low noise amplifiers and passed through filters to improve S/N ratio.

A/D multiplexer

The input to the multiplexer is through a FET switch which is operated by a pulse. The pulse may cyclically switch on the respective switches at fixed intervals. A/D converter output goes to a A/D converter via S/H circuit is necessary before an A/D converter as the input signal not change during the process of conversion.

QUESTION BANK

LEVEL 1

1. An engineer uses an ohmmetre to measure the direct current resistance of a transformer winding measure. The engineer notices that when once of the ohmmetre lead is disconnected from the transformer, a spark results. What accounts for this phenomenon?
 - (a) Ohm's law
 - (b) Faraday's law
 - (c) Thomson effect
 - (d) Seebeck effect
2. Which of the following bridges can be used for the measurement of dielectric loss of a capacitor?
 - (a) Schering bridge
 - (b) Heaviside Campbell equal ratio voltage
 - (c) Owen bridge
 - (d) Anderson bridge
3. At a frequency below the resonant frequency...circuit is capacitive and...circuit is inductive.
 - (a) series, parallel
 - (b) parallel, series
 - (c) parallel, parallel
 - (d) series, series
4. Reactive current through the capacitive load produces...field and reactive current through the inductive load process ... field.
 - (a) magnetic, electric
 - (b) electric, magnetic
 - (c) magnetic, magnetic
 - (d) electric, electric
5. Shering bridge measures
 - (a) Capacitance, dielectric loss
 - (b) Inductance
 - (c) Resistance
 - (d) Mutual inductance
6. If the transient during switching of a power supply are to be studied, which oscilloscope will be preferred?
 - (a) An ordinary oscilloscope with high frequency sweep generator
 - (b) Dual beam oscilloscope
 - (c) Dual trace oscilloscope
 - (d) Storage oscilloscope
7. In CRT, aquadag carries
 - (a) Aqueous solution of graphite
 - (b) Sweep voltage
 - (d) Secondary emission electrons
 - (d) None of the above
8. The precision of an instrument indicates its ability to reproduce a certain reading with a given
 - (a) Drift
 - (b) Resolution
 - (c) Shift
 - (d) Consistency
9. In the context of ac bridge measurements, the term "Wagner Ground" means
 - (a) A special RC connection that eliminates stray magnetic effects
 - (b) Any unwanted and unintended ground connection
 - (c) A large metal plate buried in the ground and connection to one corner of the bridge
 - (d) A special RC connection that eliminates stray capacitance effects
10. The resolution of a logic analyser is
 - (a) The maximum number of input channels
 - (b) The maximum duration of the glitch it can capture
 - (c) Its internal clock period
 - (d) The minimum amplitude of input signal it can display
11. While transporting a sensitive galvanometre
 - (a) The terminals are kept shorted
 - (b) Critical damping resistance is connected across the terminals
 - (c) The terminals are kept open-circuited
 - (d) It does not matter as to what is connected across the terminals
12. Harmonic distortion for each frequency can be obtained by harmonic analyser of the
 - (a) heterodyne type
 - (b) tuned circuit type
 - (c) fundamental suppression type
 - (d) bridge circuit type
13. The most serious source of error in A.C. bridge measurement is
 - (a) eddy currents
 - (b) leakage currents
 - (c) residual imperfectness
 - (d) stray fields
14. De-Sauty bridge is more widely used because of
 - (a) Simplicity
 - (b) Perfect balance for imperfect capacitors
 - (c) Perfect balance for air capacitors
 - (d) Maximum sensitivity
15. The phenomenon of creeping occurs in
 - (a) Energy metres
 - (b) Ammetres
 - (c) Watt metres
 - (d) Voltmetres
16. Potentiometre method of dc voltage measurement is in principle, more accurate than direct measurement of a voltage using voltmeter because
 - (a) It loads the circuit to the maximum extent
 - (b) It loads the circuit moderately
 - (c) It does not load the circuit at all
 - (d) It uses zero center galvanometre instead of a voltmeter
17. Which one of the following statements is true?
 - (a) Alternating voltage and current waveforms contain even and odd harmonics in general
 - (b) The inductance in a circuit reduces the amplitude of the harmonic in the current wave and makes it more nearly to the sinusoidal wave shape than the voltage wave

- (c) Alternating a voltage and current waveforms in general, do not contain odd harmonics
 (d) The inductance in the circuit does not affect, the wave shapes at all
18. Insertion of a dielectric material in between the plates of an air capacitor
 (a) Increases the capacitance
 (b) Decreases the capacitance
 (c) Has an effect whatsoever
 (d) Increases the breakdown
19. Pointing vector wattmetre uses
 (a) Seebeck effect (b) Ferranite effect
 (c) Induction effect (d) Hall effect
20. Thermistors are made of
 (a) Pure metals
 (b) Pure insulators
 (c) Sintered mixtures of metallic oxides
 (d) Pure semiconductor
21. A permanent magnet moving coil measures the
 (a) True rms value (b) DC value
 (c) Peak value (d) rms plus dc value
22. To measure low resistance four-terminal approach is preferred because it
 (a) Eliminates the effect of thermoelectric emf
 (b) Minimizes the effect of parasitic capacitances
 (c) Reduces the effect of parasitic inductances
 (d) Eliminates the effect of lead and contact resistance
23. A dual trace oscilloscope usually offers two modes, chop and alternate. The alternate mode can be used for displaying
 (a) Any two waveforms
 (b) Two waveforms of relatively high frequency
 (c) Two waveforms of relatively low frequency
 (d) One low frequency and one high frequency waveform
24. Wagner earthing device eliminates the effects of
 (a) All stray capacitances in the bridge network
 (b) Stray capacitance between components
 (c) Stray capacitance between the detector terminals to the ground
 (d) The mutual coupling between components
25. Kelvin double bridge is chosen to measure low resistance because
 (a) It has high sensitivity
 (b) Thermoelectric emf's can be taken
 (c) Resistance variation due to temperature can be accounted for
 (d) Resistance variation due to contacts of leads can be eliminated
26. Which one of the following measuring instruments consume the LOWEST power from the source during measurement?
 (a) Permanent magnet moving coil
 (b) Electronic multi metre
 (c) Electrostatic instrument
 (d) Moving iron instrument
27. The use of thermocouple metres for A.C. measurement leads to a metre-scale which is
 (a) Linear (b) Square law
 (c) Logarithmic (d) Exponential
28. A dynamometer type of wattmetre is connected in an A.C. circuit. The power indicated by the wattmetre is the
 (a) rms power (b) average power
 (c) peak power (d) instantaneous power
29. A special voltmeter can be devised which can measure the amplitude of a signal at two points in a circuit and simultaneously measure the phase difference between the voltage waveforms at these points. Such a metre would be a
 (a) Phase metre (b) Waveform metre
 (c) Vector voltmeter (d) Digital voltmeter
30. The temperature coefficient of resistance for a thermistor is
 (a) Low and negative (b) Low and positive
 (c) High and negative (d) High and positive
31. Bridges suitable for the measurement of an unknown inductance in terms of a known capacitance would include
 (a) Maxwell and Hay (b) Maxwell and Schering
 (c) Hay and Schering (d) Maxwell, Hay and Schering
32. Rectifier Moving coil instruments respond to
 (a) Peak value, irrespective of the nature of the waveform
 (b) Average value, for all waveforms
 (c) rms value for all waveforms
 (d) rms value, for symmetrical square waveforms
33. An advantage which a VTVM has over a non-electronic voltmeter is
 (a) Lower power consumption
 (b) Lower input impedance
 (c) The ability to measure wider ranges of voltage and resistance
 (d) Greater portability
34. A compensated wattmetre has its reading corrected for error due to
 (a) The frequency
 (b) Friction
 (c) Power consumed in current coil
 (d) Power consumed in potential coil
35. While measuring power in a three-phase load by two-wattmeter method, the reading of the two wattmeter will be equal and opposite when
 (a) Power factor is unity
 (b) Load is balanced
 (c) Phase angle is between 60° and 90°
 (d) The load is purely inductive
36. A polarized electrolytic capacitor can be used
 (a) Only sinusoidal circuits
 (b) In dc and sinusoidal ac circuits
 (c) Only in dc circuits
 (d) In circuits having any arbitrary waveform of current

37. The natural frequency of vibration of a reed used in a vibrating reed frequency metre, can be increased by
 - (a) Increasing the gap between the reed and the electromagnet
 - (b) Decreasing the gap between the reed and the electromagnet
 - (c) Increasing the length of the reed
 - (d) Decreasing the length of the reed
38. In noise-level measurement, the output of the microphone pick-up is weighted suitably by electrical filters so as to
 - (a) Provide linearised response at different frequencies
 - (b) Provide frequency spectra at different frequencies
 - (c) Filter the radio frequency interference
 - (d) Provide a response similar to that of the human ear
39. Galvanometre type recorders use
 - (a) Vibration galvanometre
 - (b) Ballistic galvanometre
 - (c) D'Arsonval galvanometre
 - (d) Tangent galvanometre
40. Electronic voltmeter provides more accurate readings in high resistance circuit as compared to a non-electronic voltmeter because of its
 - (a) High V/ohm ratings
 - (b) High ohm/V ratings
 - (c) Low metre resistance
 - (d) High resolution
41. Data buffering means
 - (a) A buffer stock of data already stored in a computer unit
 - (b) An electronic circuit which is used to maintain level of data
 - (c) That data are first collected in an external unit and then processed into the computer
 - (d) Application of buffer (unit gain amplifier) at interface to the computer
42. Swamping resistance is a resistance which is added to the moving coil of a metre to
 - (a) Reduce the full-scale current
 - (b) Reduce the temperature error
 - (c) Increase the sensitivity
 - (d) Increase the field strength
43. Three resistance of a shunt for a precision grade ammeter can be best measured by
 - (a) De Sauty bridge
 - (b) Schering bridge
 - (c) Maxwell bridge
 - (d) Kelvin double bridge
44. Which one of the following has the highest accuracy?
 - (a) Standard resistance
 - (b) Standard inductance
 - (c) Standard capacitance
 - (d) Standard mutual inductance
45. An indicating instrument is more sensitive if its torque to weight ratio is
 - (a) Much larger than unity
 - (b) Of the order of unity
 - (c) Much less than unity
 - (d) Made deflection –dependent
46. In a flux metre, the controlling torque is
 - (a) Produced by weights attached to the moving coil
 - (b) Produced by spring
 - (c) Not provided at all
 - (d) Provided by crossed coil mechanism
47. Dummy strain gauge is used in conjunction with the main strain gauge to
 - (a) Calibrate the system
 - (b) Compensate temperature effects
 - (c) Improve sensitivity
 - (d) Reduce strain on the gauge
48. Half effect device can be used to
 - (a) Multiply two signals
 - (b) Divide one signal by another on an instantaneous basis
 - (c) Add two signals
 - (d) Subtract one signal from another
49. Doppler shift principle is used in the measurement of
 - (a) temperature
 - (b) frequency
 - (c) speed
 - (d) pressure
50. In distortion factor metre, the filter is used to suppress
 - (a) dc component
 - (b) odd harmonics
 - (c) even harmonics
 - (d) fundamentals
51. The bandwidth requirement of an FM telemetry channel is
 - (a) Equal to that of an AM telemetry channel
 - (b) Smaller than that of an AM telemetry channel
 - (c) About 100 times of an AM telemetry channel
 - (d) About ten times that of an AM telemetry channel
52. The recording head in a magnetic tape responds to
 - (a) Electrical signal and creates a magnetic signal
 - (b) Thermal signal and creates a magnetic signal
 - (c) Magnetic signal and creates an electron signal
 - (d) Thermal signal and creates an electron signal
53. Which one of the following techniques is adopted to reduce the self-inductance of a wire-wound standard resistor?
 - (a) Bifilar winding
 - (b) Negative impedance converter
 - (c) Force balance type flux compensation
 - (d) Providing additional potential terminals
54. A fixed resistor of suitable value is usually connected across a thermistor to
 - (a) Decrease its resistance
 - (b) Increase its sensitivity
 - (c) Compensate its self-heating effect
 - (d) Improve linearity
55. The main advantage in using a three OP-AMP instrumentation amplifier over a single OP-AMP differential amplifier lies in
 - (a) Higher values of CMRR
 - (b) Lower noise figure
 - (c) Elimination of the need for accurate matching of resistors
 - (d) Simplicity of gain adjustment

56. The shunt type ohmmetre is not suitable for high resistance measurements because
 (a) Very low resistance of the metre would short the high unknown resistance
 (b) Scale is highly cramped for high resistance values
 (c) Full scale value of the metre may be exceeded
 (d) Battery cannot supply the necessary current for proper metre deflection
57. Which one of the following terms is not associated with a sample-and-hold circuit?
 (a) Conversion time (b) Acquisition time
 (c) Aperture time (d) Sample mode
58. Holes are drilled on the opposite sides of disc of an induction type energy metre to
 (a) Avoid creep on no load
 (b) Balance the disc
 (c) Dissipate heat energy due to eddy currents
 (d) Increase the deflecting torque
59. The zero-suppression in recorders implies
 (a) Recording signals with reference to a point other than zero
 (b) Removing the static component so that rest of the signal is displayed with more expansion
 (c) Providing inertialess components to improve transient response
 (d) Designing the recorder for zero error
60. Suppose the potential and current coil of a wattmetre are changed accidentally and supply is given. Then
 (a) Wattmetre will not read
 (b) Current coil will burn out
 (c) Potential coil will burn out
 (d) Nothing will happen
61. A photo-cell is illuminated by a small bright source placed one metre away. When the same source of light is placed two metres away. The electrons emitted by the photocathode
 (a) Each carry one quarter of their previous energy
 (b) Each carry one quarter of their previous momenta
 (c) Are half as numerous
 (d) Are one quarter as numerous
62. In terms of LMTQ system of dimensional parameters, the dimension of 'permittivity' can be expressed as
 (a) $L^{-3} M^{-1} T^2 Q^2$ (b) $L^{-1} M^{-1} T^2 Q^2$
 (c) $L^2 M T^{-1} Q^{-1}$ (d) $L^{-2} M^{-1} T^2 Q^2$
63. In hygrometers the principle of measurements is
 (a) change in resistance of salts with humidity
 (b) change in microwave power using klystron
 (c) change in thermal conductivity using thermistor
 (d) none of the above
64. The input impedance of a CRO is nearly
 (a) Zero (b) Around 10 ohms
 (c) Around 100 ohms (d) Around one mega-ohm
65. If the transients during switching of a power supply are to be studied, which oscilloscope will be preferred?
 (a) All ordinary oscilloscope with high frequency sweep generator
 (b) Dual beam oscilloscope
 (c) Dual trace oscilloscope
 (d) Storage oscilloscope
66. In a dual beam oscilloscope
 (a) There are two separate vertical input and two separate horizontal inputs
 (b) There are two separate vertical inputs and there is only one set of horizontal deflection plates
 (c) There is only one vertical input but there are two separate horizontal deflection plates
 (d) There is only vertical and one horizontal input
67. Which of the following is not an advantage of semi-conductor strain gauges as compared to conventional strain gauges?
 (a) Excellent hysteresis characteristics
 (b) Least sensitive to temperature changes
 (c) High fatigue life
 (d) Smaller size
68. The capacitance and loss angle of a capacitor can be accurately measured by
 (a) Kelvin's bridge (b) Anderson's bridge
 (c) Schering bridge (d) Carey-Foster's bridge
69. Which one of the following sets of building blocks mainly decides the accuracy of a frequency counter?
 (a) Crystal and ADC
 (b) ADC and DAC
 (c) DAC and gate width generator
 (d) Gate width generator and crystal
70. LDC displays are preferred over LED displays because they
 (a) are more reliable (b) consume less power
 (c) respond quickly (d) are cheaper
71. Which one of the following statements correctly represents the post acceleration in a Cathode-Ray Tube?
 (a) It provides deflection of the beam
 (b) It increases the brightness of the trace if the signal frequency is higher than 10 MHz
 (c) It accelerates the beam before deflection
 (d) It increases the brightness of the trace of low frequency, signal
72. In a single-phase power factor metre, the controlling torque is
 (a) Provided by spring control
 (b) Provided by gravity control
 (c) Provided by stiffness of suspension
 (d) Not required
73. Time division multiplexing is used when the data to be transmitted is
 (a) Slow changing
 (b) Of small bandwidth
 (c) Slow changing and has a small bandwidth
 (d) Fast changing and has a wide bandwidth

74. If an induction type energy metre runs fast, it can be slowed down by
 - (a) Lag adjustment
 - (b) Light load adjusting
 - (c) adjustment the position braking magnet and moving it closer to the centre of the disc
 - (d) adjustment the position of braking magnet and moving it away it from the centre of the disc
75. The circuit generally used in digital instruments to convert sine waves into rectangular pulses is a
 - (a) sawtooth generator
 - (b) differential amplifier
 - (c) sample and hold circuit
 - (d) Schmitt trigger
76. Spectrum analyser is a combination of
 - (a) Narrow band superheterodyne receiver and CRO
 - (b) Signal generator and CRO
 - (c) Oscillator and wave analyser
 - (d) VTVM and CRO
77. The reflecting mirror mounted on the moving coil of a vibration galvanometer is replaced by a bigger size mirror. This will result in
 - (a) Lower frequency of resonance and lower amplitude of vibration
 - (b) Low frequency of resonance but the amplitude of vibration is unchanged
 - (c) Higher frequency of resonance and lower amplitude of vibration
 - (d) Higher frequency of resonance but the amplitude of vibration is unchanged
78. Which of the following statements is not correct for a storage type oscilloscope?
 - (a) The storage target is a conductive mesh covered with magnesium fluoride
 - (b) Secondary emission electrons etch a positively charged pattern
 - (c) The flood guns used for display emit high velocity electrons
 - (d) The flood guns are placed between the deflection plates and storage target
79. In calibration of a dynamometre Wattmetre by potentiometre, phantom loading arrangement is used because
 - (a) The arrangement gives accurate results
 - (b) The power consumed in calibration work is minimum
 - (c) The method gives quick results
 - (d) The onsite calibration is possible
80. Which of the following transducers is classified as an active transducer?
 - (a) Metallic strain gauge
 - (b) Capacitive microphone
 - (c) LVDT
 - (d) Piezoelectric transducer
81. Torque/Weight ratio of an instrument indicates
 - (a) Selectivity
 - (b) Accuracy
 - (c) Fidelity
 - (d) Sensitivity
82. Decibel scales is useful while measuring voltages covering
 - (a) Wide frequency ratio
 - (b) Wide voltage ratio
 - (c) Narrow frequency range
 - (d) Narrow voltage range
83. The difference between the indicated value and the true value of a quantity is
 - (a) Gross error
 - (b) Absolute error
 - (c) Dynamic error
 - (d) Relative error
84. Vibration galvanometres, tuneable amplifier and head phones are used in
 - (a) DC bridges
 - (b) AC bridges
 - (c) Both DC and AC bridges
 - (d) Kelvin double bridge
85. Which one of the following multi-range voltmeters has high and constant input impedance?
 - (a) Permanent magnet moving coil voltmeter
 - (b) Electronic voltmeter
 - (c) Moving iron voltmeter
 - (d) Dynamometer type voltmeter
86. Which one of the following truly represents the output on the screen of spectrum analyzer when an amplitude modulated wave is connected to it?
 - (a) Single vertical lines on the screen
 - (b) Two vertical lines on the screen
 - (c) Three vertical lines with amplitude
 - (d) Three vertical lines out of which two have equal magnitude
87. The capacitance and loss angle of a given capacitor specimen are best measured by
 - (a) Wheatstone bridge
 - (b) Maxwell bridge
 - (c) Anderson bridge
 - (d) Schering bridge
88. The energy capacity of a storage battery is rated in
 - (a) kwh
 - (b) kw
 - (c) Ampere hours
 - (d) Joules
89. The pressure coil of an induction type energy metre is
 - (a) Highly resistive
 - (b) Highly inductive
 - (c) Purely resistive
 - (d) Purely inductive
90. Pair of active transducer is
 - (a) Thermistor; Solar cell
 - (b) Thermocouple; Thermistor
 - (c) Thermocouple; Solar cell
 - (d) Solar cell; LVDT
91. Sensitivity of LVDT is mainly due to
 - (a) Magnetic shielding of the core
 - (b) Permeability of the core
 - (c) Exact cancellation of secondary voltages
 - (d) Insulation used in the winding

92. Integrating principle in the digital measurement is the conversion of
 (a) Voltage to time (b) Voltage to frequency
 (c) Voltage to current (d) Current to voltage
93. The correct sequence of the blocks in an analog data acquisition unit starting from the input is
 (a) Transducer-Recorder-Signal-conditioner
 (b) Transducer-Signal-Conditioner-Recorder
 (c) Signal-Conditioner-Transducer-Recorder
 (d) Signal-Conditioner-Recorder-Transducer
94. For defining the standard metre, wavelength of which material is considered?
 (a) Neon (b) Krypton
 (c) Helium (d) Xenon
95. The materials to be used in the manufacture of a standard resistance should be of
 (a) High resistivity
 (b) Low resistivity
 (c) High temperature coefficient
 (d) Low resistivity and high temperature coefficient
96. The voltage coil of a single-phase house service energy metre
 (a) Is highly resistive
 (b) Is highly inductive
 (c) Is highly capacitive
 (d) Has a phase angle equal to load power factor angle
97. Piezo-electric crystal is generally employed for the measurement of which one of the following?
 (a) Flow (b) Velocity
 (c) Acceleration (d) Temperature
98. In a distortion factor metre, the filter at the front end is used to suppress
 (a) Odd harmonics
 (b) Even harmonics
 (c) Fundamental component
 (d) DC component
99. Wagner's earth in AC bridge circuits is used to eliminate the effect of
 (a) Stray electrostatic fields
 (b) Stray electromagnetic fields
 (c) Inter-component capacitances
 (d) Parasitic capacitance to earth
100. Magnetic flux can be measured by
 (a) Capacitor pick-up (b) Inductive pick-up
 (c) Resistance pick-up (d) Half-effect pick-up
2. A metre has full-scale deflection of 90° at a current of 1 A. The response of the metre is square-law. Assuming spring control, the current for a deflection 45° will be
 (a) 0.25 A (b) 0.50 A
 (c) 0.67 A (d) 0.707 A
3. A permanent magnet moving coil type ammeter and moving iron type ammeter are connected in series in a resistive circuit fed from output of a half wave rectifier voltage source. If the moving iron type instrument reads 5 A, the permanent magnet moving coil type instrument is likely to read
 (a) Zero (b) 2.5 A
 (c) 3.18 A (d) 5 A
4. The coils having self-inductances of 10 mH and 15 mH have an effective inductance of 40 mH, when connected in series-aiding. What will be the equivalent inductance if we connect them in series-opposing?
 (a) 20 mH (b) 10 mH
 (c) 5 mH (d) Zero
5. In a digital voltmeter, the oscillator frequency is 400 kHz and the ramp voltage falls from 8 V to 0 V in 20 ms. The number of pulses counted by the counter is
 (a) 800 (b) 2000
 (c) 4000 (d) 8000
6. Pulses of a frequency of 1 MHz are applied to the time base selector of a digital frequency metre which consists of 6 frequency dividers, each dividing the incoming frequency by a factor of 10. The time-base setting at the output of 4th frequency divider starting from the input is
 (a) 1 ms (b) 10 ms
 (c) 100 ms (d) 1 s
7. The maximum percentage quantization error for a 12-bit analog to digital converter is
 (a) $\pm 0.00076\%$ (b) $\pm 0.012207\%$
 (c) $\pm 3.125\%$ (d) $\pm 4.17\%$
8. In two-wattmeter method of power measurement, one of the wattmeters will show negative reading when the load pf angle is strictly
 (a) less than 30° (b) less than 60°
 (c) greater than 30° (d) greater than 60°
9. A zero to 300 V voltmeter has an error of $\pm 2\%$ of the full-scale deflection. If the true voltage is 30 V, then the range of readings on this voltmeter would be
 (a) 20 V to 40 V (b) 24 V to 36 V
 (c) 29.4 V to 30.6 V (d) 29.94 V to 30.06 V
10. A component manufacturer produces certain resistors which have a resistance value anywhere between 1.14 k Ω and 1.26 k Ω and classifies them as 1.2 k Ω resistors. If the resistance values are specified at 25°C and resistance have temperature coefficient of $+500\text{ PPM}/^\circ\text{C}$. Then the maximum resistance that one of these components might have at 75°C is
 (a) 1.1111 k Ω (b) 1.2915 k Ω
 (c) 1.5959 k Ω (d) 1.7575 k Ω

LEVEL 2

1. An average response rectifier type electronic AC voltmeter has a DC voltage of 10 V applied to it. The metre reading will be
 (a) 7.1 V (b) 10.0 V
 (c) 11.1 V (d) 22.2 V

11. A slide wire potentiometer has 10 wires of 1 m each. With the help of a standard voltage source of 1.018 V it is standardized by keeping the jockey at 101.8 cm. If the resistance of the potentiometer wires is 1000 ohm, then the value of the working current is
 - (a) 0.1 mA
 - (b) 0.5 mA
 - (c) 1 mA
 - (d) 10 mA
12. A PMMC zero to 10 A ammetre is not provided with any controlling mechanism and the moving part are free to rotate. If a current of 1 A dc is passed through the moving coil, then the instrument
 - (a) will read 1 A
 - (b) will read 10 A
 - (c) pointer will continually rotate
 - (d) pointer will remain stationary
13. A PMMC instrument uses a coil of resistance 0.2 ohm and produces full-scale deflection with a steady current of 10 A. If this instrument is used as an ammetre without the addition of any external resistance then the range of the instrument will be zero to
 - (a) 0.2 A
 - (b) 1 A
 - (c) 2 A
 - (d) 10 A
14. If Q_e is the effective Q of the coil, C is the resonance capacitance and C_d is the distributed capacitance then the true Q in a Q-metre will be
 - (a) $Q_e[(C + C_d)/C]$
 - (b) $Q_e[C/(C + C_d)]$
 - (c) $Q_e[C_d/(C + C_d)]$
 - (d) $Q_e[(C + C_d)/C_d]$
15. A Q-metre is supplied with an oscillator having a 500 mV output voltage. While testing an unknown inductor, the voltage across the variable capacitance of the Q-metre, measured by a VTVM, is obtained as 10 V. The Q-factor of the inductor is
 - (a) 5
 - (b) 10
 - (c) 20
 - (d) 100
16. The voltmeter of choice for measuring the emf of a 100 V DC source would be
 - (a) 100 V, 1mA
 - (b) 100 V, 2 mA
 - (c) 100 V, 10k Ω /V
 - (d) 100 V, 100 Ω /V
17. A single-phase energy metre is operating on 230 V, 50 Hz supply with a load of 20 A for two hours at upf. The metre makes 1380 revolutions in that period. The metre constant is
 - (a) 695 rev/kWh
 - (b) 150 rev/kWh
 - (c) 0.15 rev/kWh
 - (d) 1/150 rev/kWh
18. In a digital voltmeter, 'over-ranging' implies that
 - (a) The next four digits are switched on
 - (b) 1/2 digit is switched off
 - (c) 1/2 digit is switched on
 - (d) An over-range indicator starts glowing
19. A current transformer has a phase error of +3°. The phase angle between primary and secondary currents is
 - (a) 3°
 - (b) 177°
 - (c) 180°
 - (d) 183°
20. A 230 V, 10 A, single-phase energy metre makes 90 revolutions in 3 minutes at half load rated voltage and unity pF. If the metre constant is 1800 revolutions/kWh, then its error at half load will be
 - (a) 13.04% slow
 - (b) 13.04% fast
 - (c) 15% slow
 - (d) 15% fast
21. A strain gauge bridge measures the strain in a cantilever where the gauge is fixed. With strain ϵ , the gauge resistance increases from 110 Ω to 110.52 Ω . If the gauge factor is 2.03, then strain in the cantilever will be
 - (a) 2.06×10^{-3}
 - (b) 3.15×10^{-3}
 - (c) 3.81×10^{-3}
 - (d) 4.33×10^{-3}
22. A circuit draws a current I when a single phase ac voltage V is applied to it. If the power factor is $\cos \phi$ then the dimensions of $VI \cos \phi$ would be
 - (a) ML^3T^{-2}
 - (b) ML^2T^3
 - (c) ML^3T^3
 - (d) ML^2T^{-3}
23. The current 'I' through a resistance R is measured with the following uncertainties $I = 4A \pm 0.5\%$ $R = 100 \Omega \pm 0.2\%$. If power is computed from these two measured quantities, the uncertainty in the power computed will be
 - (a) $\pm 0.01\%$
 - (b) $\pm 0.29\%$
 - (c) $\pm 0.7\%$
 - (d) $\pm 1.2\%$
24. A current $i = (10 + 10 \sin t)$ amperes is passed through an ideal moving iron type ammetre, its reading will be
 - (a) zero
 - (b) 10 A
 - (c) $\sqrt{150}$ A
 - (d) $\sqrt{2}$ V
25. In a Q-metre, an inductor tunes to 2 MHz with 450 pF and to 4 MHz with 90 pF. The distributed capacitance of the inductor is
 - (a) 30 pF
 - (b) 45 pF
 - (c) 90 pF
 - (d) 360 pF
26. If the reading of the two wattmetres are equal and positive in two-wattmetre method, the load pf in a balance 3-phase 3-wire circuit will be
 - (a) Zero
 - (b) 0.5
 - (c) 0.866
 - (d) Unity
27. A symmetrical square wave voltage is read on an average response electronic voltmeter whose scale is calibrated in terms of rms values of a sinusoidal wave. The error in the reading is
 - (a) -3.9%
 - (b) +3.9%
 - (c) -11%
 - (d) +11%
28. The emf is measured for a junction temperature different of 20°C by thermocouples made from materials A, B and C. The pair A-B gives an emf of 165 μ V, with the end of A being positive. The pair B-C gives 100 μ V, with the end of C being positive. The pair A-C will give
 - (a) 265 μ V with the end of A being positive
 - (b) 265 μ V with end of C being positive
 - (c) 65 μ V with the end of A being positive
 - (d) 65 μ V with the end of C being positive
29. A 150 V moving iron voltmeter of accuracy class 1-0 reads 75 V when used in a circuit under standard conditions. The maximum possible percentage error in the reading is
 - (a) 0.5
 - (b) 1.0
 - (c) 2.0
 - (d) 4.0

30. A 50 Hz AC voltage is measured with moving iron voltmeter and a rectifier type ac voltmeter connected in parallel. If the metre readings are V_1 and V_2 respectively and the metres are free from calibration errors, then the form factor of the ac voltage may be estimated as
- (a) $\frac{V_1}{V_2}$ (b) $1.11 \frac{V_1}{V_2}$
 (c) $2 \frac{V_1}{V_2}$ (d) $\pi \frac{V_1}{2V_2}$
31. The resistances of two coils of a wattmeter are 0.01 ohm and 1000 ohms respectively and both are non-inductive. The load current is 20 A and the voltage across the load is 30 V. In one of the two ways of connecting the voltage coil, the error in the reading would be
- (a) 0.1% too high (b) 0.2% too high
 (c) 0.15% too high (d) zero
32. Two-wattmeter method is employed measure power in a 3-phase balanced system with the current coils connected in the A and C lines. The phase sequence is ABC. If the wattmeter with its current coil in A-phase line reads zero, then the power factor of the 3- phase load will be
- (a) zero lagging (b) zero leading
 (c) 0.5 lagging (d) 0.5 leading
33. In a particular form of frequency metre, a 1 μ F capacitor is connected across a symmetrical square wave signal of 1 volt peak value. If the average value of the current taken by the capacitor, after full wave rectification is measured as 2 mA, then the frequency of the signal will be
- (a) $1000/\pi$ Hz (b) 500 Hz
 (c) 1000 Hz (d) 1000π Hz
34. The metre constant of a single-phase 240 V induction watt-hour metre is 400 revolutions per kWh. The speed of the metre disc for a current 0 to 10 amperes at 0.8 p.f. lagging will be
- (a) 12.8 rpm (b) 16.02 rpm
 (c) 18.2 rpm (d) 21.1 rpm
35. A digital voltmeter uses a 10 MHz clock and has a voltage controlled generator which provides a width of 10 μ sec per volt of unit signal. 10 volt of input signal would correspond to a pulse count of
- (a) 500 (b) 750
 (c) 1000 (d) 1500
36. An analog voltage signal whose highest significant frequency is 1 kHz is to be digitally coded with a resolution of 0.01% covering the voltage range of a to 10 volts. To avoid loss of information the MINIMUM number of bits in the digital code should be
- (a) 4 (b) 8
 (c) 10 (d) 14
37. A thermocouple ammeter gives full scale deflection at 10 A. When it reads one fifth of the scale, the current will be
- (a) 2 A (b) 4 A
 (c) 4.47 A (d) 5.78 A
38. How many time base circuits does a dual trace CRO have?
- (a) 1 (b) 2
 (c) 3 (d) 4
39. A Lissajous pattern on an oscilloscope has 5 horizontal tangencies and 2 vertical tangencies. The frequency of the horizontal input is 1000 Hz. What is the frequency of the vertical input?
- (a) 400 Hz (b) 2500 Hz
 (c) 4000 Hz (d) 5000 Hz
40. The ratio of the readings of two wattmeters connected to measure power in balanced 3 phase load is 5 : 3 and the load is inductive. The power factor of load is
- (a) 0.917 lead (b) 0.917 lag
 (c) 0.6 lead (d) 0.6 lag
41. The number of flip flops required in a decade counter is
- (a) 2 (b) 3
 (c) 4 (d) 10
42. The resistance of thermistor is 5000 Ω at 20°C and its resistance temperature coefficient is 0.04/°C. A measurement with a lead resistance of 10 Ω will cause an error of
- (a) 0.05°C (b) 0.1°C
 (c) 0.4°C (d) 0.8°C
43. In a digital voltmeter, the oscillator frequency is 400 kHz, the ramp voltage falls from 8 V to 0 V in 20 msec. The number of pulses counted by the counter is
- (a) 8000 (b) 4000
 (c) 3200 (d) 1600
44. In two watt metres method of measurements if one of the wattmeters reads zero, then what will be the power factor?
- (a) Zero (b) Unity
 (c) 0.5 (d) 0.866
45. A dc-supply of 35V is connected across 600 Ω resistance in series with an unknown resistance. The voltmeter having a resistance of 1.2k Ω is connected across 600 Ω resistance which reads 5V. Then the unknown resistance should be
- (a) 50 Ω (b) 1.7 Ω
 (c) 7.2 Ω (d) 2.4 Ω
46. A digital voltmeter has read-out range from 0 to 9999 counts. When full scale reading is 9.999 V, the resolution of the full scale reading is
- (a) 0.001 (b) 1000
 (c) 2 digit (d) 1 mV
47. Which of the following does not have the same units as the others? The symbols have their usual meanings.
- (a) L/R (b) RC
 (c) $\sqrt{LC}$ (d) $[1/\sqrt{LC}]$
48. The quantity $[1/\sqrt{\epsilon_0 \mu_0}]$ is SI units has the
- (a) Value 330m/s (b) Value 1.73×10^4
 (c) Dimensions LT^{-1} (d) None of the above
49. An alternating current source having voltage $E = 110 \sin(\omega t + \pi/3)$ is connected in an AC circuit. If the current drawn

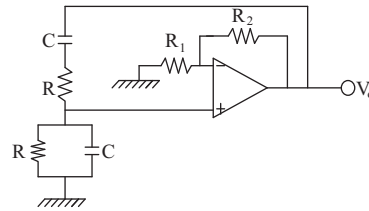
from the circuit varies as $I = 5 \sin(\omega t - \pi/3)$, impedance of the circuit will be

- (a) 22 ohms (b) 16 ohms
(c) 30.8 ohms (d) None of the above
50. The energy spent in moving a charge of 10 coulomb from one point 'a' to another point 'b' is 50 joules. The potential difference between points 'a' and 'b' is
(a) 2 volts (b) 5 volts
(c) 10 volts (d) 100 volts
51. In a set-up for the determination of self-capacitance of a coil, the standard variable capacitor has a value of 460 pF at 2 MHz and a value of 100 pF at 4MHz. The coil self-capacitance is
(a) 2 pF (b) 20 pF
(c) 60 pF (d) 200 pF
52. The coil of a moving iron voltmeter has a resistance of 200 ohms and an inductance of 0.3 H. It is connected in series with a swamping resistance of 2000 ohms. The capacitor connected in shunt with the swamping resistance for making the metre read correctly at dc as well as at 50Hz ac will have a value of
(a) 0.0125 μF (b) 0.0311 μF
(c) 0.0521 μF (d) 0.0622 μF
53. With a variable tachometer having 60 rotor teeth, the counter 3600 counts per minute. The device speed, in rpm, would be
(a) 36 (b) 60
(c) 360 (d) 3600
54. The percentage limiting error, in the case of an instrument of 8.3 v with a 0 to 150 voltmeter having a guaranteed accuracy of 1% full-scale reading is
(a) 1.810% (b) 0.181%
(c) 18.10% (d) 0.0018%
55. It is desired of convert a 0-1000 μA metre moment, with an internal resistance of 100 ohms, into a 0-100 mA metre. The required value of shunt resistance is about
(a) 1 ohm (b) 10 ohms
(c) 99 ohms (d) 100 ohms
56. A moving coil ammeter has a fixed shunt of 0.02-ohm resistance. If the coil resistance of the metre is 1000 ohms, a potential difference of 500 mV is required across it for full-scale deflection. Under this condition, the current in the shunt would be
(a) 2.5 A (b) 25 A
(c) 0.25 A (d) 0.025 A
57. The internal resistance of a -25-0-25 μA metre can be safely measure by using a laboratory multimeter whose sensitivity is
(a) 1 k ohm/volt (b) 10 k ohm/volt
(c) 100 k ohm/volt (d) 20 k ohm/volt
58. A peak-responding ac voltmeter employing a half-wave precision rectifier has been calibrated to give a reading of 1 V for 1 V rms sinusoidal input. For 1 V dc input, the metre reading will be
(a) 0.707 V (b) 0.707 V or 0 V
(c) 1.414 V (d) 1.414 V or 0 V
59. The Lissajous pattern observed on the screen of a CRO is a straight line inclined at an angle of 45° to the x-axis. If the voltage applied to the x-plate is $2 \sin \omega t$, then the voltage applied to the y-plates will be
(a) $2 \sin \omega t$ (b) $2 \sin(\omega t + 45^\circ)$
(c) $2 \sin(\omega t - 45^\circ)$ (d) $2(2)^{1/2} \sin(\omega t + 45^\circ)$
60. An oscilloscope has an input impedance consisting of 1 M Ω and 20 pF in parallel. A high impedance probe connected to the input of this oscilloscope has a 10 M Ω series resistance
(a) Need not be shunted
(b) Should be shunted by a 2 pF capacitor
(c) Should be shunted by a 20 pF capacitor
(d) Should be shunted by a 200 pF capacitor
61. In a digital measuring device, if the input electrical signal is in the frequency range dc to f_{max} Hz, then it must be sampled at a rate of
(a) f_{max} time/sec (b) $f_{max}/2$ times/sec
(c) every $2f_{max}$ sec (d) $2f_{max}$ times/sec
62. If the secondary burden of a current transformer is 15 VA and the secondary current is 5 A, then the impedance to the connected load will be
(a) 0.6 ohms (b) 5 ohms
(c) 6 ohms (d) 10 ohms
63. A diaphragm, has a natural frequency of 30 KHz. If both is the diameter and thickness are halved, then the natural frequency will be
(a) 15 kHz (b) 60 kHz
(c) 120 kHz (d) 240 kHz
64. Four voltmeters have the following specification. If accuracy is the main consideration, which one of these voltmeter should one select?
(a) 100 V; 2 m A (b) 100V; 100 ohm/volt
(c) 100 V; 1 m A (d) 10,000 V; 10 m A
65. A straight conductor 1 metre long is moved at right angles to a uniform field of 1 Wb/m² at a speed of 50 cm per second. The emf induced in the conductor is
(a) 0.5 V (b) 0.1 V
(c) 1 V (d) 5 V
66. A 1 mA ammeter has a resistance of 100 ohms. It is to be converted into a 1A ammeter. The value of shunt resistance required is
(a) 0.001 Ω (b) 0.1001 Ω
(c) 100 Ω (d) 10000 Ω
67. A 0 to 200 V dc moving coil voltmeter has a guaranteed accuracy of 0.75% of full-scale reading. The voltage measured by instrument is 100 V. The limiting error is
(a) 3% (b) 2%
(c) 1.5% (d) 0.75%
68. An average responding rectifier type electronic ammeter has its scale calibrated in terms of the rms value of a sine wave. If wave voltage of peak magnitude 100 V is measured using this voltmeter will be reading indicated by the metre?
(a) 11 V (b) 100 V
(c) 90.90 V (d) 70.7 V

69. The function of the reference electrode in a pH metre is to
- Produce a constant voltage
 - Provide temperature compensation
 - Provide a constant current
 - Measure average pH value
70. The most light sensitive transducer for conversion of light into electrical power is the
- Photodiode
 - Solar cell
 - Photoconductive
 - Photovoltaic cell
71. A coil would behave as
- An inductor at high frequency
 - A capacitor at very low frequencies
 - A capacitor at very high frequencies
 - A resistor at high frequency
72. Hot wire anemometre is a device used to measure the
- Pressure in gases
 - Liquid discharge
 - Gas velocities
 - Temperature
73. The piezoelectric crystal voltage sensitivity is defined as
- Voltage developed per unit stress
 - Field developed per unit stress
 - Voltage developed per unit force
 - Field developed per unit force
74. Consider the following statements associated with electrical/electronic transducers:
- Mass inertia effects are minimized
 - These transducers consume very little power
 - The response time is large
 - Transmission and processing the signal for the purpose of measurement are easier
- Select the correct answer using the codes given below:
- Codes:
- 1, 2 and 3
 - 2, 3 and 4
 - 1, 3 and 4
 - 1, 2 and 4
75. Gauge factor of a strain gauge is defined as the ratio of a per unit change in the
- Conductivity to the per unit change in applied force acting on the element.
 - Resistance to the per unit change in the length of the element.
 - Stress to the per unit change in strain of the element.
 - Current to the per unit change in the length of the element.
76. Which one of the following is the best definition of accuracy?
- It is the measure of consistency or reproducibility of measurements.
 - It is the ratio of the change in output signal to the change in input signal.
 - It is the smallest change in measurable input.
 - It is the closeness with which an instrument reading approaches the true value of the quantity measured
77. The most suitable primary standard for frequency is
- Rubidium vapour standard
 - Quartz standard
 - Hydrogen maser standard
 - Cesium beam standard
78. Horizontally mounted moving iron instruments employ
- Eddy current damping
 - Air friction damping
 - Fluid friction damping
 - Electromagnetic damping
79. The true r.m.s voltmeter employs two thermocouples in order to
- prevent drift
 - increase the accuracy
 - increase the sensitivity
 - cancel out the non-linear effects of first thermocouple
80. A certain oscilloscope with 4 cm by 4 cm screen has its own sweep output fed to its input. If the x and y sensitivities are same, the oscilloscope will display a
- saw-tooth wave
 - triangle wave
 - diagonal line
 - horizontal line

LEVEL 3

1. A Wien bridge oscillator is shown in the figure below:

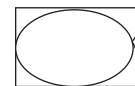


- For $R = 1 \text{ K}$,
 $C = [1/2\pi] \mu\text{F}$, $f = 1 \text{ kHz}$
- For $R = 3 \text{ K}$,
 $C = [1/18\pi] \mu\text{F}$, $f = 1 \text{ kHz}$
- The gain of the op. amp stage should be less than two for proper operation
- The gain of the op. amp stage should be three for proper operation

Which of the following statements are true, if f is the frequency of oscillation?

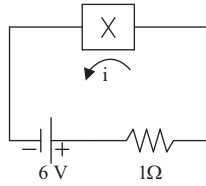
- 1 and 2
- 2 only
- 1, 2 and 4
- 2, 3 and 4

2. A Lissajous pattern, as shown in the figure below, is observed on the screen of a CRO when voltages of frequencies F_x and F_y are applied to the x and y plates respectively. $F_x : F_y$ is then equal to

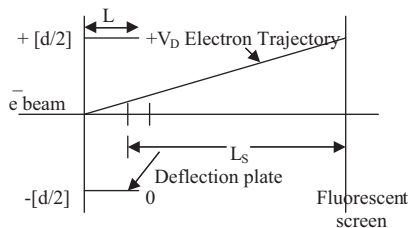


- 3 : 2
- 1 : 2
- 2 : 3
- 2 : 1

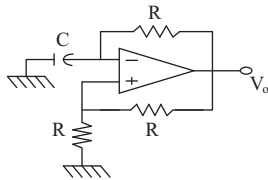
3. In the circuit shown in the figure below is an element which always absorbs power. During a particular operations, it sets up a current of 1 amp in the directions shown and absorbs P_x . It is possible that X can absorb the same power P_x for another current i , the value of this current is



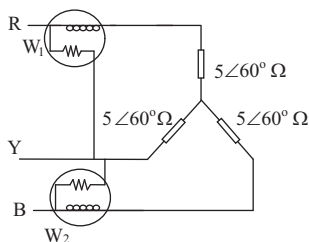
- (a) $(3 - \sqrt{14})$ amps (b) $(3 + \sqrt{14})$ amps
(c) 5 amps (d) none of the above
4. Figure shows the electrostatic vertical deflection system of CRT. Given that V_A is the accelerating voltage, the deflection sensitivity (deflection/volt) is proportional to



- (a) $\frac{LL_s}{dV_A}$ (b) $\frac{LL_s V_D}{dV_A}$
(c) $\frac{LL_s}{d} V_A$ (d) $\frac{dL_s}{LV_A}$
5. For the oscillator circuit shown in the figure, the expression for the time period of oscillation can be given by (where $\tau = RC$)

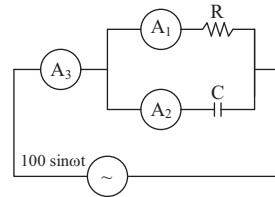


- (a) $\tau \ln 3$ (b) $2\tau \ln 3$
(c) $\tau \ln 2$ (d) $2\tau \ln 2$
6. The line-to-line input voltage to the 3 phase, 50Hz, ac circuit shown in the figure is 100 V rms. Assuming that the phase sequence is RYB, the watt-metres would read

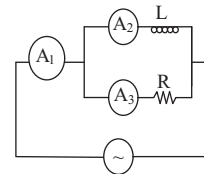


- (a) $W_1 = 886 W$ and $W_2 = 886 W$
(b) $W_1 = 500 W$ and $W_2 = 500 W$
(c) $W_1 = 0 W$ and $W_2 = 1000 W$
(d) $W_1 = 250 W$ and $W_2 = 750 W$

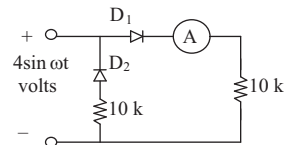
7. In the figure, A_1, A_2 and A_3 are ideal ammetres. If A_1 reads 5A, A_2 reads 12 A, then A_3 should read



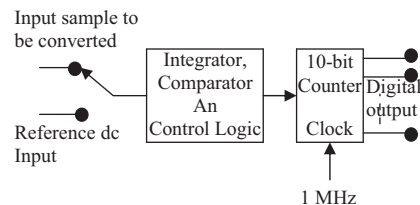
- (a) 7 A (b) 12 A
(c) 13 A (d) 17 A
8. In the figure A_1, A_2 and A_3 are ideal ammetres. If A_2 and A_3 read 3 A and 4 A respectively, then A_1 should read



- (a) 1 A (b) 5 A
(c) 7 A (d) None of the above
9. In the circuit of figure, assume that the diodes are ideal and the metre is an average indicating ammetre. The ammetre will read

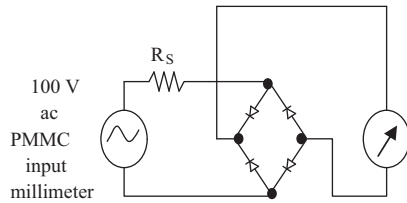


- (a) $0.4\sqrt{2} A$ (b) 0.4 A
(c) $[0.8/\pi] A$ (d) $(0.4/\pi) A$
10. The simplified block diagram of a 10-bit/D converter of dual slope integrator type is shown in the figure. The 10-bit counter at the output is clocked by a 1 MHz clock. Assuming negligible timing overhead for the control logic, the maximum frequency of the analog signal that can be converted using this A/D converter is approximately



- (a) 2 kHz (b) 1 kHz
(c) 500 Hz (d) 250 Hz

11. A rectifier type ac voltmeter consists of a series resistance R_s , and ideal full-wave rectifier bridge and PMMC instrument as shown in the figure. The internal resistance of the instrument is $100\ \Omega$ a full scale deflection is produced by a dc current of 1 mA . The value of R_s required to obtain full scale deflection with an ac voltage of 100 V (rms) to the input terminal is:

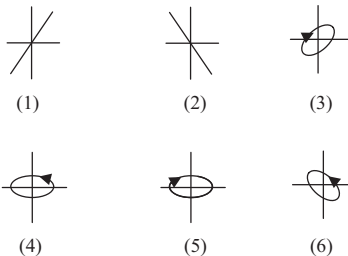


- (a) $63.56\ \Omega$
 (b) $89.93\ \Omega$
 (c) $89.93\text{ k}\Omega$
 (d) $141.3\text{ k}\Omega$
12. Group II represents the figure obtained on a CRO screen when the voltage signals $V_x = V_{xm} \sin \omega t$ and $V_y = V_{ym} \sin (\omega t + \Phi)$ are given to its X and Y plates respectively and Φ is changed. Choose the correct value of Φ from Group I to match with the corresponding figure of Group II.

Group I
P. $\Phi = 0$
Q. $\pi < \Phi < 3\pi/2$
R. $\Phi = \pi/2$
S. $\Phi = 3\pi/2$

Group II

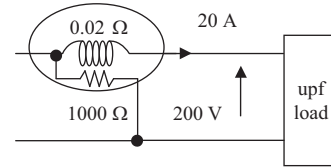
Group II



Codes:

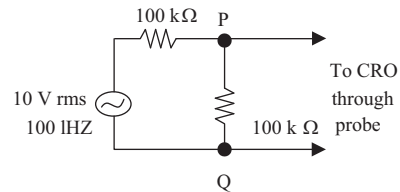
P	Q	R	S
(a) 1	3	6	5
(b) 2	6	4	5
(c) 2	3	5	4
(d) 1	6	5	4

13. The circuit in the figure is used to measure the power consumed by the load. The current coil and the voltage coil of the wattmeter have $0.02\ \Omega$ and $1000\ \Omega$ resistance respectively. The measured power compared to the load power will be



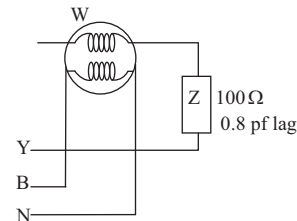
- (a) 0.4 % less
 (b) 0.2 % less
 (c) 0.2 % more
 (d) 0.4 % more

14. A CRO probe has an impedance of $500\text{ k}\Omega$ in parallel with a capacitance of 10 pF . The probe is used to measure the voltage between P and Q as shown in the figure. The measured voltage will be



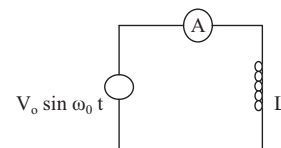
- (a) 3.53 V
 (b) 4.37 V
 (c) 4.54 V
 (d) 5.00 V

15. A single-phase load is connected between R and Y terminals of a 415 V , symmetrical, 3-phase, 4 wire system with phase sequence RYB. A wattmeter is connected in the system as shown in the figure the power factor of the load is 0.8 lagging. The wattmeter will read



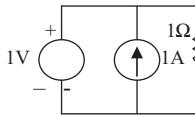
- (a) -795 W
 (b) -597 W
 (c) $+597\text{ W}$
 (d) $+795\text{ W}$

16. When a voltage $V_o \sin \omega_o t$ is applied to the pure inductor, the ammetre shown in the figure reads I_o . If the voltage applied is $-V_o \sin \omega_o t + 2V_o \sin 2\omega_o t + 3V_o \sin 3\omega_o t + 4V_o \sin 4\omega_o t$, the ammetre reading would be



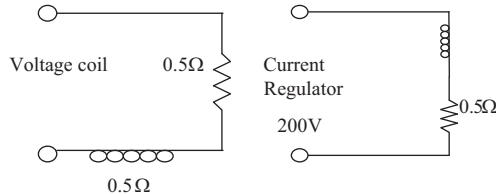
- (a) 0
 (b) $10 I_o$
 (c) $\sqrt{4^3 + 3^3 + 2^3 + 1} I_o$
 (d) $2 I_o$

17. What will be the power consumed by the voltage source, current source and resistance respectively?



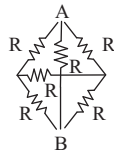
- (a) 1W, 1W, 2W (b) 0W, 1W, 1W
(c) 1W, 0W, 1W (d) 0W, 0W, 0W

18. A 200 V, 5A wattmetre is tested on full load using the circuit shown in the figure. The power consumed for testing is



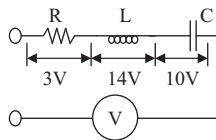
- (a) 8W (b) 25W
(c) 33W (d) 1000W

19. When all the resistance in the circuit are of one each, the equivalent resistance across the points A and B will be



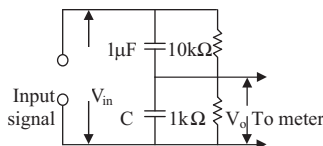
- (a) 1 R (b) 0.5 R
(c) 2 R (d) 1.5 R

20. The source in the circuit shown is a sinusoidal source. The voltage across various elements are marked in the figure. The input voltage is



- (a) 10 V (b) 5 V
(c) 27 V (d) 24 V

21. The arrangement shown in the given figure represents an RC potentiometer for measuring ac voltage. What should be the value of C so that V_o/V_{in} is independent of the frequency of the input signal?



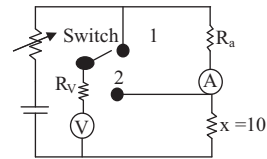
- (a) 10 μF (b) 11 μF
(c) 0.10 μF (d) 0.09 μF

22. Consider the circuit shown in the given figure for the measurement of resistance X using voltmeter-ammeter method.

Ammeter resistance, $R_a = 0.1\Omega$

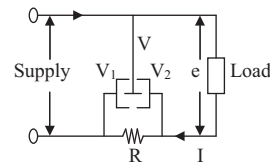
Voltmeter resistance, $R_v = 5000\Omega$

If X_1 and X_2 are the measured values of X for switch positions 1 and 2 respectively, then the arithmetic mean of X_1 and X_2 will be



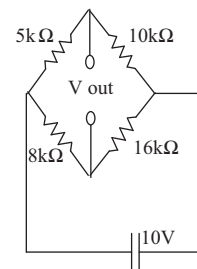
- (a) 9.98 Ω (b) 10.00 Ω
(c) 1004 Ω (d) 10.10 Ω

23. In the circuit of an electrostatic wattmetre given below, the instantaneous torque is proportional to



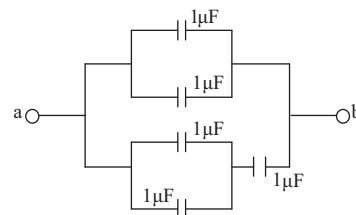
- (a) $ei + [i^2 R/2]$ (b) $ei - [i^2 R/2]$
(c) $ei + i^2 R$ (d) $ei - i^2 R$

24. In the Wheatstone bridge shown in the given figure, if the resistance in each arm is increased by 0.05% then the value of V_{out} will be



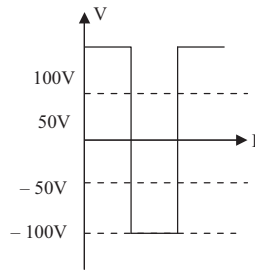
- (a) 50 mV (b) 5 mV
(c) 0.1V (d) zero

25. The total capacitance across points 'a' and 'b' in the given figure is

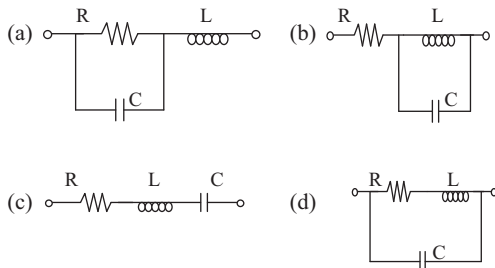


- (a) 1.66 μF (b) 2.66 μF
(c) 3.5 μF (d) 4.5 μF

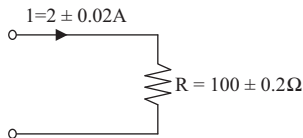
26. A voltage waveform shown in the given figure is applied to an ideal full-wave rectifier voltmeter. The voltmeter is calibrated to read the RMS values of sine waves. The voltmeter will read



- (a) $50/(2)^{1/2}$ (b) $100/(2)^{1/2}$ V
(c) 100 V (d) 111 V
27. The equivalent circuit of a wire-wound resistor can be represented as



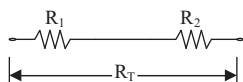
28. The current flowing through the resistor R is as indicated in the given figure. The computed value of power is



- (a) 400 ± 0.42 W (b) 400 ± 4.60 W
(c) 400 ± 8.85 W (d) 400 ± 10.65 W
29. The equivalent series resistance of a capacitor (C) in terms of its power factor and operation frequency (f) is given by

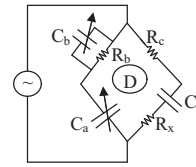


- (a) Power factor/ $2\pi fC$
(b) $2\pi fC$ /Power factor
(c) $2\pi fC$ (Power factor)
(d) $1/2\pi fC$ (Power factor)
30. Two resistances R_1 and R_2 are connected as shown in the given figure. If $R_1 = 528 \pm 5\Omega$ & $R_2 = 325 \pm 3\Omega$ then the total resistor R_T will be



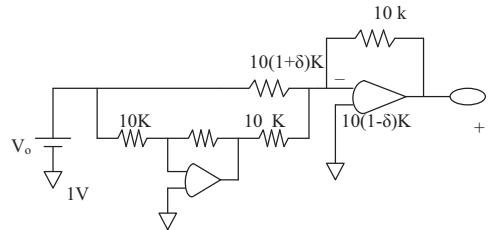
- (a) $853 \pm 2\Omega$ (b) $853 \pm 5\Omega$
(c) $853 \pm 3\Omega$ (d) $853 \pm 8\Omega$

31. In the bridge shown in the given figure, the value of R_x and C_x at balance will be

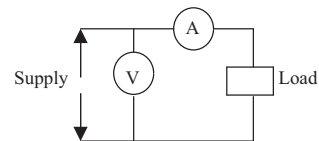


- (a) $R_x = \frac{C_b}{C_a} R_c$, $C_x = \frac{R_b}{R_c} C_a$
(b) $R_x = \frac{C_a}{C_b} R_c$, $C_x = \frac{R_c}{R_b} C_a$
(c) $R_x = \frac{C_a}{C_b} R_c$, $C_x = \frac{R_b}{R_c} C_a$
(d) $R_x = \frac{C_b}{C_a} R_c$, $C_x = \frac{R_c}{R_b} C_a$

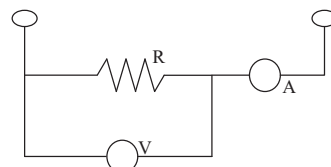
32. The circuit shown in the given figure is that of a half-bridge which is often used if only two identical resistive transducers are employed, for example two strain gauges. For $\delta \ll 1$ the output V_0 will be



- (a) δ (b) 2δ
(c) -2δ (d) $-\delta$
33. In the circuit shown in the figure, if the voltmeter and ammetre are interchanged, it is likely to result in damage to

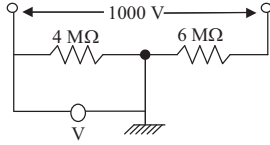


- (a) Both the instruments (b) The ammetre
(c) The voltmeter (d) Neither of less instruments
34. The set-up in the figure is used to measure resistance R. The ammetre and voltmeter resistances are 0.01Ω and 2000Ω , respectively. Their readings are 2 A and 180 V, respectively, giving a measure resistance of 90Ω . The percentage error in the measurement is

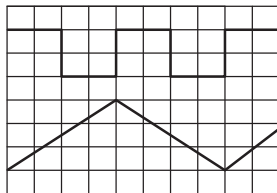


- (a) 2.25 % (b) 2.35 %
(c) 4.5 % (d) 4.71 %

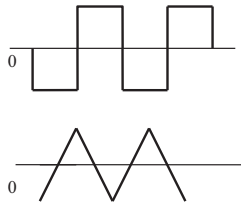
35. A 1000 V DC supply has two 1-core cables as its positive and negative leads: their insulation resistance to earth are $4\text{ M}\Omega$ and $6\text{ M}\Omega$, respectively, as shown in the figure. A voltmeter with resistance of $50\text{ k}\Omega$ is used to measure the insulation of the cable. When connected between the positive core and earth, then voltmeter reads



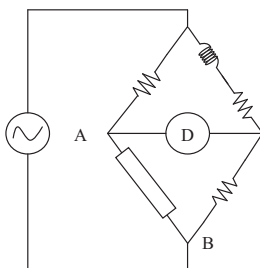
- (a) 8 V (b) 16 V
(c) 24 V (d) 40 V
36. The time/div and voltage/div axes of an oscilloscope have been erased. A student connects a 1 kHz, 5 p-p square wave calibration pulse to channel 1 of the scope and observe the screen to be as shown in the upper trace of the figure. An unknown signal is connected to channel 2 (lower trace) of the scope. If the time/div and V/div on both channel are the same, the amplitude (p-p) and period of the unknown signal are respectively



- (a) 5 V, 1 ms (b) 5 V, 2 ms
(c) 7.5 V, 2 ms (d) 10 V, 1 ms
37. A sampling wattmetre (that computes power from simultaneously sampled values of voltage and current) is used to measure the average power of a load. the peak to peak voltage of the square wave is 10 V and the current is a triangular wave of 5 A p-p as shown in the figure. The period is 20 ms. The reading in W will be

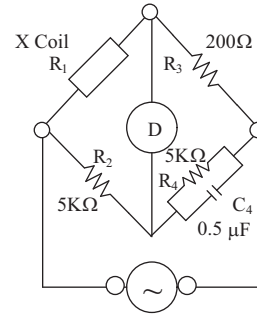


- (a) 0 W (b) 25 W
(c) 50 W (d) 100 W
38. Below figure shows a balanced ac bridge excited by a voltage source of fixed frequency.

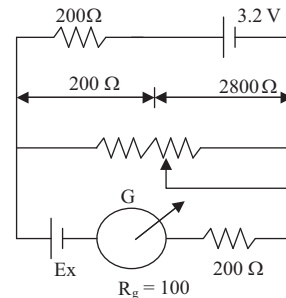


- (a) An R and L in series
(b) An R and C in series
(c) An R and C in parallel
(d) An R and L in parallel

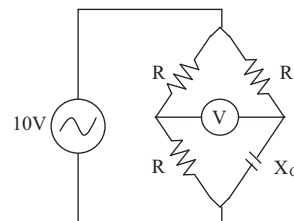
39. In the A.C. bridge circuit shown in the figure, at balance, the parametres of the coil are calculated to the 50 mH and 20Ω . Another coil is connected in parallel to the previous coil, and balance is restored by changing R_2 to $2.5\text{ k}\Omega$. The parametres of the new coil are than



- (a) 25 mH, 20Ω
(b) 50 mH, 10Ω
(c) 50 mH, 20Ω
(d) 100 mH, 40Ω
40. In the potentiometric circuit shown in the figure, balance is obtained. The unknown E_x is then

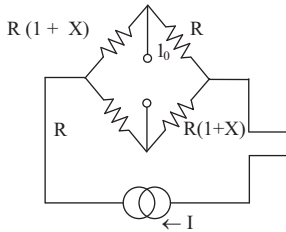


- (a) 20 mV (b) 2.8 V
(c) 3.0 V (d) 400 mV
41. In the bridge circuit shown in the figure, when $[X_C/R] = 1$, the voltmeter reads

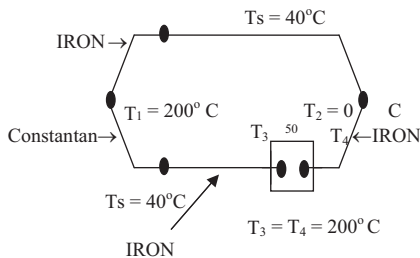


- (a) 5 V (b) 0.0 V
(c) 2.5 V (d) 10 V

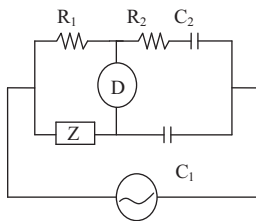
42. For the circuit given in figure the unbalance voltage e_0 is



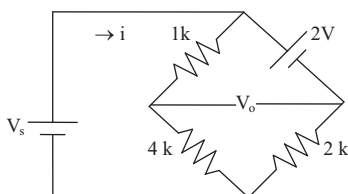
- (a) $e_0 = IRX$ (b) $e_0 = [IRX/2]$
 (c) $e_0 = 2 IRX$ (d) $e_0 = IR (1 + X)$
43. The extension wires of iron constantan thermocouple were improperly wired shown in the figure
 The voltmeter calibrated in $^{\circ}\text{C}$ will then read



- (a) 240 (b) 180
 (c) 14C (d) 120
44. The A.C. bridge in the figure remains balanced if Z comprises of

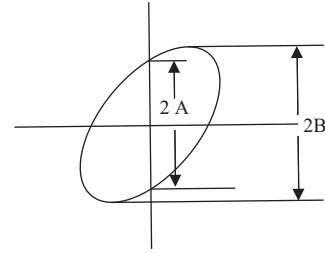


- (a) Resistance only
 (b) Capacitance only
 (c) Resistance and capacitance in parallel
 (d) Resistance and inductor in series
45. The bridge circuit in the figure is balanced. The magnitude of current I is



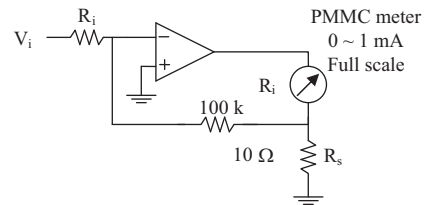
- (a) 2 mA (b) 4 mA
 (c) 5 mA (d) 6 mA

46. The elliptical Lissajous pattern shown in the figure was observed from two sinusoidal signal sources of same frequency on a CRO



The phase angle between the signals is

- (a) $\cos^{-1}\left(\frac{A}{B}\right)$ (b) $\tan^{-1}\left(\frac{A}{B}\right)$
 (c) $\sin^{-1}\left(\frac{A}{B}\right)$ (d) $\left(\frac{A}{B}\right)$
47. In the DC millivoltmeter circuit shown in the figure, the input for full scale deflection is



- (a) 10 V (b) 1 V
 (c) 100 mV (d) 10 mV
48. The time base of a high frequency CRO whose screen diameter is 10 cm is set at $10 \mu \text{ sec/cm}$. The lowest frequency of the signal that can be fully displayed on this CRO for measurement and analysis with great accuracy is
- (a) Greater than 100 kHz
 (b) Equal to 100 kHz
 (c) Equal to 10 kHz
 (d) Less than 10 kHz
49. An instrument needs an amplifier to amplify pulse of one microsecond duration. This amplifier must have a bandwidth of at least
- (a) 10 kHz (b) 10 MHz
 (c) 1 kHz (d) 1 MHz
50. The semiconductor strain gauge has gauge factor
- (a) 2 (b) 10
 (c) 100 (d) 1000
51. The gauge factor of strain gauge is 2, stress is 1050 kg/cm^2 , $Y = 2.1 \times 10^6 \text{ kg/cm}^2$ and R is 1000 ohms. The value of ΔR will be
- (a) 2Ω (b) 3Ω
 (c) 4Ω (d) 1Ω
52. A temperature sensitive transducer is subjected to a sudden temperature change. It takes 10 seconds for the transducer to reach equilibrium condition (five time constants). The time

taken by the transducer to read half of the temperature difference will be nearly

- (a) 1.38 second (b) 5.00 second
(c) 8.62 second (d) 9.8 second
53. If the reference sound pressure level is 2×10^{-5} N/m² then a sound pressure of 90 dB will be equal
(a) 0.632 N/m² (b) 0.707 N/m²
(c) 0.835 N/m² (d) 0.925 N/m²
54. A capacitance transducer has two plates of area 5 cm² each, separated by an air gap of 2 mm. Displacement sensitivity (in pF/cm) due to gap change would be
(a) 11.1 (b) 44.2
(c) 52.3 (d) 66.3
55. A hall-effect transducer with Hall coefficient $K_H = -1 \times 10^{-8}$ is required to measure a magnetic field of 10,000 gauss. A 2 mm bismuth slab is used as the transducer with of 3A. The output voltage of the transducer will be
(a) -7.5×10^{-6} V (b) -1.5×10^{-6} V
(c) -20×10^{-4} V (d) -22.5×10^{-4} V
56. The resistance of a 125 ohm strain gauge changes by one ohm for 4000 micro strain. The gauge factor of the strain gauge is
(a) 1.5 (b) 2
(c) 2.5 (d) 3
57. The dead-zone of certain pyrometre is 0.125% of the span. The calibration is 400°C to 1000°C. What temperature change might occur before it is detected?
(a) 0.125°C (b) 0.75°C
(c) 0.4°C (d) 1°C
58. In restriction type flow measuring devices, if the differential pressure is ΔP , the flow will be proportional to
(a) ΔP (b) $1/\Delta P$
(c) $\sqrt{\Delta P}$ (d) $1/\sqrt{\Delta P}$
59. A wire strain gauge element subjected to a strain has a gauge factor of 2, a resistance of 125 ohms and is of 1m length. For a change in length of the wire by 0.005 m, the change in the resistance will be
(a) 0.25 ohm (b) 0.5 ohm
(c) 1.25 ohm (d) 2.5 ohm
60. An accelerometre has a seismic mass of 0.05 kg and a spring constant 3×10^3 N/m. The maximum permissible displacement of the mass is ± 1 mm. The maximum measurable acceleration is
(a) 30 m/s² (b) 60 m/s²
(c) 90 m/s² (d) 120 m/s²
61. A 24 mm long conductor has resistance of 128 ohms. If the change in resistance is 13.3 ohms and the changes in length is 1.6 mm under tension, then the gauge factor of the conductor will be approximately
(a) 1.2 (b) 1.6
(c) 2.1 (d) 2.6
62. A wattmetre has a range of 1000 W with an error of $\pm 1\%$ of full scale deflection. If the true power passed through it is 100 W, then relative error would be

- (a) $\pm 10\%$ (b) $\pm 5\%$
(c) $\pm 1\%$ (d) $\pm 0.5\%$
63. A resistance strain gauge is fastened to a beam subjected to a strain of 1×10^{-6} , yielding a resistance change of 240 $\mu\Omega$. If the original resistance of the strain gauge is 120 Ω the gauge factor would be
(a) 5 (b) 2
(c) 1 (d) 0.2
64. A voltage of $200\sqrt{2} \sin 314t + 6\sqrt{2} \sin (942t + 30^\circ) + 8\sqrt{2} \cos (1570t + 30^\circ)$ V is given to a harmonic distortion metre. The metre will indicate a total harmonic distortion of approximately
(a) 4.5% (b) 6.5%
(c) 7.5% (d) 8.5%
65. If the largest frequency present in the measured signal and number of bits used in the binary code are respectively ' f_m ' and ' n ' then the minimum bandwidth of a pulse code modulation channel used for telemetry would be
(a) $\frac{f_m}{2n}$ (b) $\frac{f_m}{n}$
(c) $n f_m$ (d) $2n f_m$
66. A DC circuit can be represented by an internal voltage source of 50 V with an output resistance of 100 k Ω . In order to achieve accuracy better than 99% for voltage measurement across its terminals, the voltage measuring device should have a resistance of atleast
(a) 10 M Ω (b) 1 M Ω
(c) 10 k Ω (d) 1 k Ω
67. In $I_1 = y_{11}V_1 + y_{12}V_2$ the inductance of pressure coil produces error. The error is
(a) Constant irrespective of the power factor of the load
(b) Higher at higher power factor loads
(c) Higher at lower power factor loads
(d) Highest at unity power factor loads
68. An analogue voltage signal whose highest significant frequency is 1 KHz is to be coded with a resolution of 0.01 percent for a voltage range of 0–10 V. The minimum sampling frequency and the minimum number of bits should respectively be
(a) 1 kHz and 12 (b) 1 kHz and 14
(c) 2 kHz and 12 (d) 2 kHz and 14
69. A spring controlled moving iron voltmeter draws a current of 1 mA for full scale value of 100 V. If it draws a current of 0.5 mA, the metre reading is
(a) 25 V (b) 50 V
(c) 100 V (d) 200 V
70. In the measurement of power on balanced load by two-Wattmetre method in a 3 phase circuit, the readings of the Wattmetre are 3 kw and 1 kW respectively, the latter being obtained after reversing the connections of the current coil. The power factor of the load is
(a) 0.277 (b) 0.554
(c) 0.625 (d) 0.866

71. In a stroboscopic method of rotational speed measurements of a machine shaft

N = the machine shaft speed of rotation of the shaft in revolutions/min

N = No. of points on the circular pattern

F = No. of flashes per min.

The speed of rotation N will be

- (a) $N = F + n$ (b) $N = F - n$
 (c) $N = \frac{F}{n}$ (d) $N = F \cdot n$
72. To reduce the effect of noise level, 100 sets of data are averaged. The averaged. Data set will have a noise level reduced by a factor of
 (a) 10 (b) $10\sqrt{2}$
 (c) $50\sqrt{2}$ (d) 100
73. If K is the number of parity provided with a message, the number of errors which can be detected are
 (a) K
 (b) $K - 1$
 (c) $K + 1$
 (d) dependent upon the number of bits in the message also
74. A Wien-bridge is used to measure the frequency of the input signal. However the input signal has 10 % third harmonic distortion. Specifically the signal is $2 \sin 400 \pi t + 0.2 \sin 1200 \pi t$ (with t in sec.) With this input the balance will
 (a) Lead to null indication and setting will correspond to a frequency of 200 Hz
 (b) Lead to null indication and setting will correspond to 260 Hz
 (c) Lead to null indication and setting will correspond to 400 Hz
 (d) Not lead to null indication.
75. In a Q-metre measurement to determine the self-capacitance of a coil, the first resonance occurred at f_1 with $C_1 = 300 \text{ pF}$. The second resonance occurred at $f_2 = 2f_1$ with $C_2 = 60 \text{ pF}$. The self capacitance of coil works out to be
 (a) 240 pF (b) 60 pF
 (c) 360 pF (d) 20 pF
76. Three dc voltmeters are connected in series across a 120 V dc supply. The voltmeters are specified as follows:
 The voltage read by the metre A , B , and C respectively
 Voltmeter A : 100 V, 5 mA
 Voltmeter B : 100 V, 250 ohms/V
 Voltmeter C : 10 mA, 15000 ohms

The voltage read by the metres A , B and C are respectively

- (a) 40, 50 and 30 V
 (b) 40, 40 and 40 V
 (c) 60, 30 and 30 V
 (d) 30, 60 and 30 V
77. A strain gauge with a resistance of 250 ohms undergoes a change of 0.150 ohm during a test. The strain is 1.5×10^{-4} . Then the gauge factor is
 (a) 2.0 (b) 3.0
 (c) 4.0 (d) 100
78. What is the range for a $3\frac{1}{2}$ digital metre?
 (a) 0 to 1999 (b) 0 to 1500
 (c) 0 to 999 (d) 0 to 19999
79. A moving-coil instrument gives full scale deflection for 1 mA and has a resistance of 5Ω . If a resistance of 0.55Ω is connected in parallel to the instrument, what is the maximum value of current it can measure?
 (a) 5 mA
 (b) 10 mA
 (c) 50 mA
 (d) 100 mA
80. A single slide wire is used for the measurement of current in a circuit. The voltage drop across a standard resistance of 1.0Ω is balanced at 70 cm. What is the magnitude of the current, if the standard cell having an e.m.f of 1.45 volts is balanced at 50 cm?
 (a) 3.09 A (b) 2.65 A
 (c) 2.03 A (d) 1.45 A
81. What is the series resistance required to extend the 0 – 100 V range of a $20000 \Omega/\text{V}$ metre to 0 – 1000 V?
 (a) $10 \text{ M}\Omega$ (b) 16Ω
 (c) $18 \text{ M}\Omega$ (d) $20 \text{ M}\Omega$
82. One cycle of a square wave signal observed on an oscilloscope is found to occupy 6 cm at a scale setting of $30 \mu\text{s}/\text{cm}$. What is the signal frequency?
 (a) 1.8 kHz (b) 5.55 kHz
 (c) 18 kHz (d) 55.5 kHz
83. A moving coil has a resistance of 10 ohms and takes 40 mA to produce full-scale deflection. The shunt resistance required to convert this instrument for use as an ammeter of range 0 to 2A is
 (a) 0.1021Ω (b) 0.2041Ω
 (c) 0.2561Ω (d) 0.4210Ω

ANSWER KEYS

LEVEL 1

1. (b)	2. (a)	3. (a)	4. (b)	5. (a)	6. (d)	7. (a)	8. (d)	9. (d)	10. (d)
11. (b)	12. (a)	13. (d)	14. (a)	15. (a)	16. (d)	17. (b)	18. (a)	19. (c)	20. (c)
21. (b)	22. (d)	23. (b)	24. (c)	25. (d)	26. (c)	27. (b)	28. (a)	29. (c)	30. (c)
31. (a)	32. (b)	33. (a)	34. (d)	35. (d)	36. (c)	37. (d)	38. (a)	39. (a)	40. (b)
41. (c)	42. (b)	43. (d)	44. (a)	45. (a)	46. (c)	47. (b)	48. (a)	49. (c)	50. (d)
51. (d)	52. (a)	53. (a)	54. (d)	55. (c)	56. (b)	57. (a)	58. (a)	59. (b)	60. (b)
61. (d)	62. (a)	63. (a)	64. (d)	65. (d)	66. (b)	67. (b)	68. (c)	69. (d)	70. (b)
71. (b)	72. (d)	73. (c)	74. (d)	75. (d)	76. (a)	77. (b)	78. (c)	79. (b)	80. (d)
81. (d)	82. (a)	83. (b)	84. (b)	85. (b)	86. (d)	87. (d)	88. (c)	89. (b)	90. (c)
91. (c)	92. (b)	93. (b)	94. (b)	95. (a)	96. (b)	97. (c)	98. (c)	99. (a)	100. (d)

LEVEL 2

1. (c)	2. (d)	3. (c)	4. (b)	5. (d)	6. (b)	7. (b)	8. (d)	9. (b)	10. (b)
11. (d)	12. (b)	13. (d)	14. (a)	15. (c)	16. (c)	17. (b)	18. (d)	19. (b)	20. (c)
21. (a)	22. (d)	23. (d)	24. (c)	25. (a)	26. (d)	27. (d)	28. (c)	29. (c)	30. (b)
31. (c)	32. (c)	33. (a)	34. (a)	35. (c)	36. (b)	37. (c)	38. (a)	39. (b)	40. (b)
41. (c)	42. (a)	43. (a)	44. (c)	45. (d)	46. (d)	47. (d)	48. (c)	49. (a)	50. (b)
51. (b)	52. (d)	53. (b)	54. (c)	55. (a)	56. (b)	57. (d)	58. (b)	59. (a)	60. (b)
61. (d)	62. (a)	63. (d)	64. (d)	65. (a)	66. (b)	67. (c)	68. (a)	69. (a)	70. (a)
71. (c)	72. (b)	73. (b)	74. (d)	75. (b)	76. (d)	77. (c)	78. (b)	79. (c)	80. (c)

LEVEL 3

1. (c)	2. (b)	3. (d)	4. (c)	5. (b)	6. (c)	7. (c)	8. (b)	9. (d)	10. (b)
11. (c)	12. (d)	13. (c)	14. (a)	15. (b)	16. (d)	17. (b)	18. (c)	19. (b)	20. (b)
21. (a)	22. (c)	23. (a)	24. (d)	25. (b)	26. (d)	27. (d)	28. (c)	29. (a)	30. (d)
31. (a)	32. (b)	33. (b)	34. (d)	35. (a)	36. (c)	37. (a)	38. (d)	39. (d)	40. (a)
41. (a)	42. (b)	43. (d)	44. (c)	45. (d)	46. (c)	47. (d)	48. (c)	49. (d)	50. (a)
51. (d)	52. (a)	53. (a)	54. (a)	55. (b)	56. (b)	57. (b)	58. (c)	59. (c)	60. (b)
61. (b)	62. (a)	63. (b)	64. (a)	65. (c)	66. (a)	67. (c)	68. (d)	69. (b)	70. (a)
71. (c)	72. (c)	73. (b)	74. (d)	75. (d)	76. (a)	77. (c)	78. (a)	79. (b)	80. (c)
81. (c)	82. (b)	83. (b)							

CHAPTER

ANALOG

ELECTRONIC CIRCUITS

7.1 SMALL SIGNAL EQUIVALENT CIRCUITS OF DIODES

PN junction is formed on a single crystal of semiconductors like Ge or Si by doped acceptor impurity on one side and donor impurity on the other side.

- Current flow in PN junction diode

$$= I_o \left(e^{\frac{v}{nV_T}} - 1 \right)$$

where, I_o = Reverse saturation current
 n = Factor due to charge generation and recombination.
 $n = 1$ for Ge.
 $n = 2$ for Si

Diode

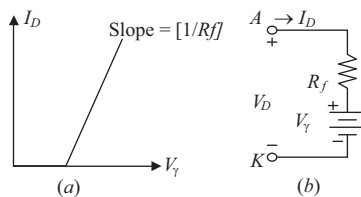


Fig. 7.1 (a) Piecewise linear diode forward characteristic
 (b) Diode model for forward bias.

7.2 SMALL SIGNAL EQUIVALENT CIRCUITS OF BJTs

Hybrid Model:

$$V_1 = h_i I_1 + h_r V_2 \leftarrow \text{KVL}$$

$$I_2 = h_f I_1 + h_o V_2 \leftarrow \text{KCL.}$$

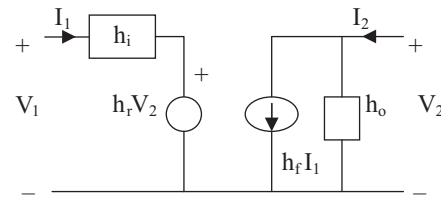


Fig. 7.2

7.3 SMALL SIGNAL EQUIVALENT CIRCUITS OF FET OR JFET/MOSFET

1. A **current-controlled device** is one in which a current defines the operating conditions of the device, whereas a **voltage-controlled device** is one in which a particular voltage defines the operating conditions.
2. The JFET can actually be used as a **voltage controlled resistor** because of a unique sensitivity of the drain-to-source impedance to the gate-to-source voltage.
3. The relationship between the drain current and the gate-to-source voltage of a JFET is a **nonlinear** one defined by **Shockley's equation**. As the current level approaches I_{DSS} , the sensitivity of I_D to changes in V_{GS} increases significantly.

Equivalent Circuit of FET at Low Frequencies

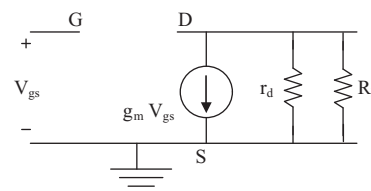


Fig. 7.3

4. The depletion-type MOSFETs have the same transfer characteristics as a JFET for drain currents up to the I_{DSS} level. At this point, the characteristics of a depletion point type MOSFET continue to levels above I_{DSS} whereas those of the JFET end.
5. The **arrow** in the symbol of **n-channel JFETs** or MOSFETs will always point into the center of the symbol, whereas those of a p-channel device will always point out of the center of the symbol.
6. The transfer characteristics of an enhancement-type MOSFET are not defined by Shockly's equation but rather by a **nonlinear equation** controlled by the gate-to-source voltage, the threshold voltage, and a constant k defined by the device employed. The resulting plot of I_D versus V_{GS} is one that rises exponentially with increasing values of V_{GS} .
7. A **CMOS** (complementary MOSFET) device is one that employs a unique combination of p-channel and n-channel MOSFETs with a single set of external leads. It has the **advantages of a very high input impedance, fast switching speeds, and low operating power levels**, all of which are very useful in logic circuits.

JFET

$$I_D = I_{DSS} \left(1 - \frac{V_{GS}}{V_P} \right)^2$$

$$I_D = I_{DSS} \Big|_{V_{GS}=0V}; I_D = 0 \text{ mA} \Big|_{V_{GS}=V_P}$$

$$I_D = \frac{I_{DSS}}{4} \Big|_{V_{GS}=V_P/2}$$

$$V_{GS} \cong 0.3V_P \Big|_{I_D=I_{DSS}/2}; V_{GS} = V_P \left(1 - \sqrt{\frac{I_D}{I_{DSS}}} \right)$$

$$P_D = V_{DS} I_D$$

$$r_d = \frac{r_0}{(1 - V_{GS}/V_P)^2}$$

MOSFET (enhancement):

$$I_D = k(V_{GS} - V_T)^2$$

$$k = \frac{I_{D(on)}}{(V_{GS(on)} - V_T)^2}$$

7.4 SIMPLE DIODE CIRCUITS

Clipper

Clipping circuits are used to select transmission for that part of an arbitrary waveform which lies above or below some particular reference voltage level. These are also called voltage or current limiters. Some typical clippings with input-output waveform are shown in the figure 7.4.

Considering diode as ideal, there can be a variety of clipper circuits.

Parallel Clippers

(a) Positive clipper

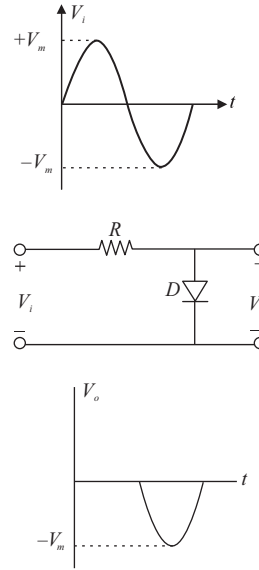


Fig. 7.4

When V_i is +ve, diode will be forward biased, since it is assumed to be ideal, it will act as a short circuit. Thus, $V_o = 0$ Volts.

When V_i is -ve, diode will be reverse biased, thus it act as a open circuit, V_o will be same as V_i .

(b) Two level clipper

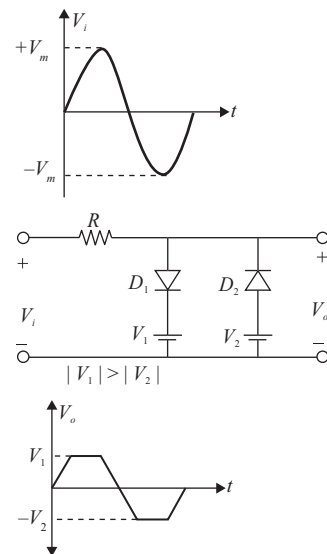


Fig. 7.5

When V_i is +ve $\rightarrow D_1$ will become forward biased.

When $V_i > V_1 \rightarrow D_2$ will be reverse biased.

When V_i is -ve $\rightarrow D_2$ will become forward biased.

When $V_i > V_2 \rightarrow D_1$ will remain reverse biased.

Clamper

The clamping circuit establishes a recurrent positive or negative extremity at some constant reference voltage level VR. The clamping circuit introduces a dc component to a waveform that has lost its dc component after passing through a capacitive coupling network. For this reason, clamping circuit is often referred to as dc restorer or dc inverter.

Wave Form

Consider the given circuit which consists of signal source V_i of neglecting output impedance, a capacitor and a diode D .

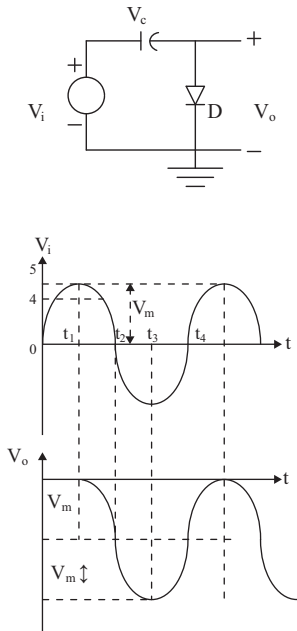


Fig. 7.6

Assuming the ideal diode i.e., $V_f = 0$ and $R_f = 0$. The input is sinusoidal. During first quarter cycle of input signal, the capacitor gets charged as the diode is forward biased. No output voltage.

$$\therefore V_o = 0.$$

At the end of first quarter cycle $V_c = V_m$. After the diode comes reverse bias, the input signal reduces but the capacitor is not able to discharge due to diode.

$$\therefore V_o = V_i - V_m.$$

(a) Negative Clamping

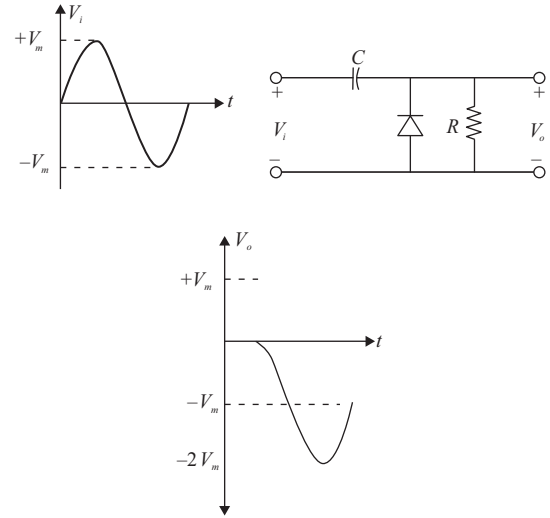


Fig. 7.7

During +ve cycle, circuit will be as given below and capacitor gets charged. During diode 'off' state, capacitor should hold its voltage level.

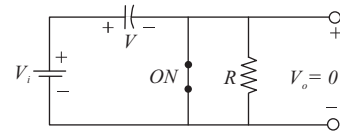


Fig. 7.8

During -ve cycle, circuit will be as

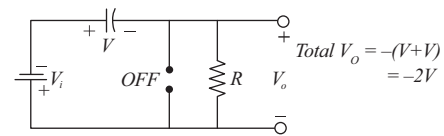


Fig. 7.9

Voltage Doubler

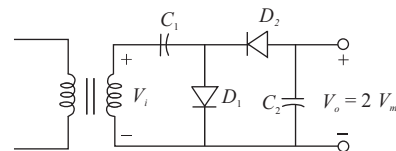


Fig. 7.10

During +ve cycle, C_1 gets charged as D_1 conduct and during -ve cycle, D_2 conduct but C_2 gets charged with $2V_m$.

Rectifiers

	HW	FW	Bridge	HW (3 ϕ)	FW (3 ϕ)
Number of diodes	1	2	4	3	6
Secondary voltage	V_m	$2V_m$	V_m	V_m	V_m
PIV	V_m	$2V_m$	V_m	V_m	V_m
V_{dc}	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$	$0.82V_m$	$0.95V_m$
r	1.21	0.482	0.482	0.17	0.055
η_{max}	40.6	81.2	81.2	96.	99.5
f_0	f_i	$2f_i$	$2f_i$	$3f_i$	$6f_i$

7.5 TRANSISTOR BIASING

The transistor is biased (with the help of external voltage) in such a manner so the Q-point is selected in the middle portion of the transistor output characteristic. When the ac voltage is superimposed, it is ensured that the positive and negative half of input voltage cycle remain in the linear or active region in the transistor characteristic. Under these conditions, the transistor output voltage is undistorted.

- To fix the Q-point, load line curve is needed.
- The dc load line is locus of variation of output voltage and output current.
- The load lines are drawn for the amplifier chosen in the active region of output of characteristic.
- The Q-point is generally fixed at the middle of load line.
- Ac load line has greater slope than dc load line.
- If the Q-point is chosen near the V_{ce} (cutoff region or I_c axis (saturation region) then output will be highly distorted.
- If the Q-point is chosen in the saturation region for NPN transistor, it may cause the output to be clipped in the positive half cycle of the input signal.

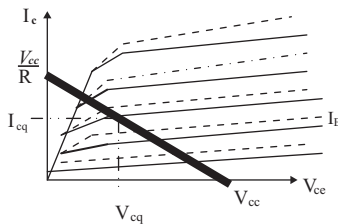


Fig. 7.11

Stabilization

Once the Q-point has been fixed due to some biasing arrangement, it has to be stabilized against the variation in:

- (a) Temperature (T) $-I_{co}$ double for every 10 degree rise in temperature.

- (b) I_b (Depends on V_{be}), i.e., V_{be} decrease at the rate of 2.5 mv/degree.

- (c) β .

- Due to variation of one or all of these parameters, I_c current will change which shifts the Q-point.
- In stabilization technique, resistive biasing circuit is used which permits I_b to vary by an amount so as to keep I_c relatively constant with variation in any of T , I_b , β .

Change in Temperature

- We know that $I_c = \beta I_b + (1 + \beta) I_{co}$
- β varies due to change in temperature.
- I_b also changes due to change in temperature. As the cut in voltage increases at 2.5 mv/degree for constant I_c .
- I_{co} changes with temperature, doubles with every 10 degree rise in temperature. Increase in I_{co} causes an increase in I_c which further increases the collector dissipation thereby increasing the collector temperature. This may set in a cumulative effect causing thermal runaway burning out the transistor ultimately.

In Si transistor, I_{co} is of the order of nano amperes compared to milliamps in Ge and so *thermal runaway* and instability is more a problem in Ge transistor.

Stability Factor

- The merit of a biasing circuit in holding the dc collector current I_c at the operating Q-point, may be examined by stability factor

$$S = \left. \frac{\delta I_c}{\delta I_{co}} \right|_{V_{be}, \beta = \text{constant}}$$

$$S_\beta = \left. \frac{\delta I_c}{\delta \beta} \right|_{I_{co}, V_{be} = \text{constant}}$$

$$S_V = \left. \frac{\delta I_c}{\delta V_{be}} \right|_{I_{co}, \beta = \text{constant}}$$

- The lower the value of stability factor (S), the better is stability of circuit.
- $1 < S < 1 + \beta$.
- The stability factor S is most important since it depends upon I_{co} and temperature.

$$S_\beta = \left. \frac{\delta I_c}{\delta I_\beta} \right|_{V_{be} = \text{Constant}}$$

$$I_c = \beta I_b + (1 + \beta) I_{co} \dots \text{general expression}$$

Differentiate with respect to I_c

$$1 = \beta \frac{\delta I_b}{\delta I_c} + (1 + \beta) \frac{\delta I_{co}}{\delta I_c}$$

$$S = \frac{\delta I_c}{\delta I_{co}} = \frac{(1 + \beta)}{(1 - \beta) \frac{\delta I_b}{\delta I_c}}$$

Fixed Bias Circuit

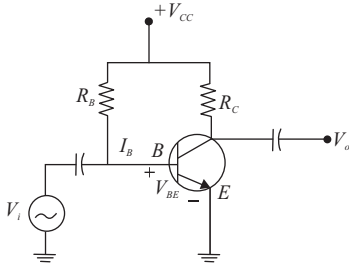


Fig. 7.12

$$I_B = (V_{CC} - V_{BE}) / R_B$$

$\alpha \rightarrow$ common base amplification factor

$$\alpha_{dc} = (I_C / I_E)$$

$$\alpha_{ac} = (\Delta I_C / \Delta I_E)$$

DC Bias Voltage Feedback/Collector to Base Binary

$$I_B = (V_{CC} - V_{BE}) / (R_B + \beta(R_C + R_E))$$

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

$$I_C = \beta I_B$$

$$S = \frac{1 + \beta}{1 + \frac{\beta R_E}{R_B + R_E}}$$

- (a) Better than fixed biased circuit.
- (b) $\beta R_E \gg R_B$ as this will give very small value as stability as near to 1.

Drawback of Collector to Base Bias

- R_B has to be very small but this gives large I_B . This increase in I_B is offset by a decrease in I_B , hence there is not much overall improvement in stability.
- Output is feedback to the base via R_E and this reduces the net gain of the transistor.

Self-Bias/Potential Divider/Emitter Bias

Voltage divider bias network

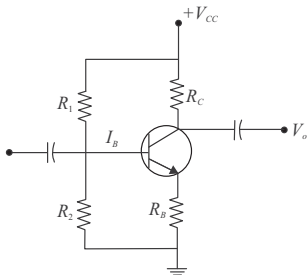


Fig. 7.13

Obtain the equivalent circuit for this bias

$$R_{th} = (R_1 R_2 / R_1 + R_2)$$

$$V_{th} = V_{CC} [R_2 / R_1 + R_2]$$

$$I_B = (V_{th} - V_{BE}) / (R_{th} + R_E)$$

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

At saturation,

$$I_{Csat} = V_{CC} / (R_C + R_E)$$

This type of bias is also called self-bias network

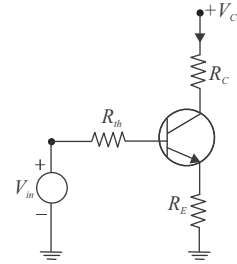


Fig. 7.14

- As compared to collector–base bias, if the load of the collector is a transformer, then R_c will be small, so $\beta R_c \gg R_b$ cannot be achieved. But self-bias is suitable for any type of load resistance.
- Emitter bias is applied by a resistor R_s between the emitter and ground, i.e., *Thevenin* equivalent of two resistor of self bias.
- When collector current increases the voltage drop across R_e increases and reduces forward bias V_{be} reducing base current I_b and keeping the operating point stable.
- Stability factor

$$S = \frac{1 + \beta}{1 + \frac{\beta R_E}{R_B + R_E}}$$

If $R_B / R_E \ll 1$, then

$$S = 1$$

- $R_E \gg R_B$,
- $S = 1$ Best stability.
- R_E introduces both dc and ac feedback.
- In order to avoid the loss of ac signal gain because of feedback caused by R_E . This R_E is bypassed by a leakage capacitor C_E of high value so that it is offering little resistance at frequency of interest.

$$S_\beta = \frac{\delta I_C}{\delta \beta}; \quad S_\beta = \frac{I_{C1} \cdot S_2}{\beta_1 (1 + \beta)}$$

$$S_V = \frac{\delta I_C}{\delta V_{be}}; \quad S_V = \frac{\beta}{R_B + R_C (1 + \beta_2)}$$

where, S_2 : Stability (S) at $\beta = \beta_2$.

Total increment in I_c is the sum of all three increments due to I_{co} , β , and V_{be} .

$$\Delta I_c = S_1 \Delta I_{co} + S_v \Delta V_{be} + S_\beta \Delta \beta.$$

Compensation Techniques

- Major disadvantage of the resistor biasing techniques is the feedback of the output signal to the input which causes reduction in gain. To avoid this, compensation techniques with diodes, transistor and thermistor are employed.
- Diode compensation

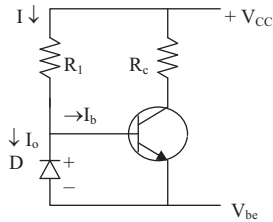


Fig. 7.15

- Reverse bias diode is connected in the base emitter circuit, which is of the same material as transistor.
- The reverse bias voltage V_{be} allows the reverse saturation current to I_o to flow through the diode D

$$I = \frac{V_{cc} - V_{be}}{R_1} = \frac{V_{cc}}{R_1}$$

$$\text{and } I_B = I - I_o$$

From collector current expression

$$I_c = \beta I_b + (1 + \beta) I_{co} = \beta I - \beta I_o + (1 + \beta) I_{co}$$

$= \beta I - \beta I_o + \beta I_{co}$ if $\beta \gg 1$ and I_o of diode and I_{co} of transistor track each other over the desired temperature range then I_{co} remains essentially constant.

Reverse saturation current I_o flows through the diode. If I_{co} increases due to temperature, the increased current flows through diode decreasing I_b keeping I_b constant.

Thermistor

Thermistors are temperature sensitive element, which has a negative temperature coefficient of resistance.

The thermistor element is placed parallel to and across V_{cc} and E . R_2 of potential divider bias. Increase of temperature reduces resistance and decrease the forward bias reduces I_b and I_c .

Sensistor Compensation

It may be placed either in parallel with R_1 or parallel with R_E . It can also be placed in the place of R_E rather than in parallel with R_E .

7.6 FET/MOSFET BIASING

For the field-effect transistor, the relationship between input and output quantities is nonlinear due to the squared term in Shockley's equation. The nonlinear relationship between I_D and V_{GS} can complicate the mathematical approach to the dc analysis of FET configurations. A graphical approach may limit solutions to tenths-place accuracy, but it is a quicker method for most FET amplifiers.

Another distinct difference between the analysis of BJT and FET transistors is that the input controlling variable for a BJT transistor is the current level, while for the FET a voltage is the controlling variable. In both cases, however, the controlled variable on the output side is the current level that also defines the important voltage levels of the output circuit.

The general relationships that can be applied to the analysis of all FET amplifiers are

$$I_G \cong 0A \text{ and } I_D = I_S$$

For JFETS and depletion-type MOSFETs, Shockley's equation is applied to relate the input and output quantities:

$$I_D = I_{DSS} \left(1 - \frac{V_{GS}}{V_P} \right)^2$$

For enhancement MOSFET

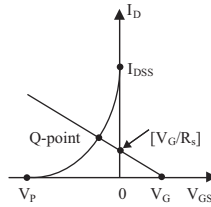
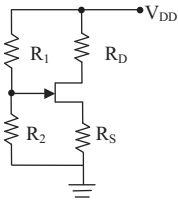
$$I_D = k (V_{GS} - V_r)^2$$

Table FET Bias Configurations

Type/configuration/ pertinent equations	Graphical solution
JFET Fixed-bias $I_G \cong 0$ $V_{GS_Q} = -V_{GG}$ $V_{DS} = V_{DD} - I_D R_D$ $R_i > 100 \text{ M}\Omega$ $C_i: (1-110) \text{ pF}$	Advantage: No loss of gain Disadvantage: Two batteries required, no negative feedback to stabilize 'Q' point

**Type/configuration/
pertinent equations**
Graphical solution

JEFT/voltage-divider bias



$$V_G = \frac{R_2 V_{DD}}{R_1 + R_2}$$

$$V_{GS} = V_G - I_D R_S$$

$$V_{DS} = V_{DD} - I_D (R_D + R_S)$$

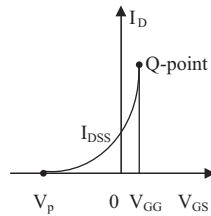
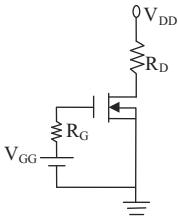
$$V_D = V_{DD} - I_D R_D$$

$$V_S = I_D R_S$$

Advantage:

- Single battery required.
–ve feedback for DC to stabilize 'Q' point
- R_2 act as a leakage path to increase I_D

Reduction in loss of gain for A.C

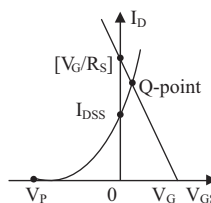
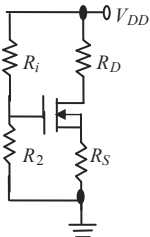
 Depletion type
MOSFET/fixed-bias


$$V_{GSQ} = +V_{GG}$$

$$V_{DS} = V_{DD} - I_D R_S$$

$$R_i > 10^{10} \Omega$$

$$C_i : (1-10) \text{ pF}$$

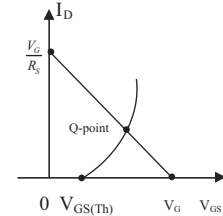
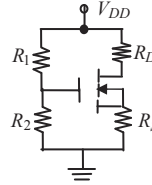
 Depletion-type MOSFET/
voltage-divider bias


$$V_G = \frac{R_2 V_{DD}}{R_1 + R_2}$$

$$V_{GS} = V_G - I_S R_S$$

$$V_{DS} = V_{DD} - I_D (R_D + R_S)$$

**Type/configuration/
pertinent equations**
Graphical solution

 Enhancement type
MOSFET/voltage-Divider
bias


$$V_G = \frac{R_2 V_{DD}}{R_1 + R_2}$$

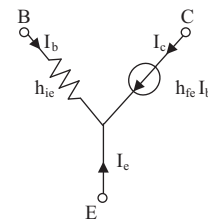
$$V_{GS} = V_G - I_D R_S$$

7.7 TRANSISTOR AMPLIFIER ANALYSIS

Approximate Analysis of Transistor

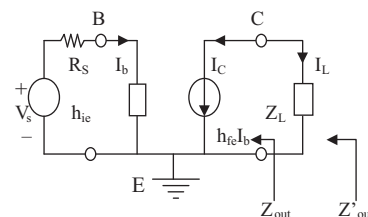
In general for a transistor if

1. $h_{oe} = 10^{-6} S$
2. $h_{re} = 10^{-4}$
3. $h_{oe} Z_L \leq 0.1$

 Then it is seen that, the error made in the analysis is $<10\%$, in such case, approximate analysis holds good for CE.

Fig. 7.16 Approximate h-model which may be used for all three configurations

$$\begin{aligned} h_{re} &= 10^{-4} & h_{oe} &= 10^{-4} S \\ h_{fe} &= 100 & h_{re} &= 2k. \end{aligned}$$

1. CE Analysis


Fig. 7.17

Features:

1. The current gain is high (h_{fe}).
2. Voltage gain is high.
3. Input and output currents are out of phase by 180° .
4. The input and output voltages are out of phase by 180° .
5. Input impedance is medium.
6. Output impedance is medium.
7. Since voltage gain and current gain both are simultaneously high, this configuration is always used as an amplifier.

2. CB Analysis

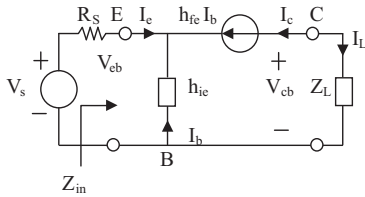


Fig. 7.18

Features:

1. Low current gain (α) $\Rightarrow$ always less than 1.
2. High voltage gain (approximately equal CE).
3. Input and output currents are in phase.
4. Input and output voltages are in phase.
5. It has lowest input impedance of all the three configurations.
6. It has highest output impedance of all the three configurations.
7. Since current gain is approximately equal to 1, it can be used as constant current source.
8. It can be used at place where transformation of impedance from a very low value to very high value is desired.
9. Non-inverting amplifier with $A_v > 1$ and $A_i < 1$.

3. CC/Emitter follower

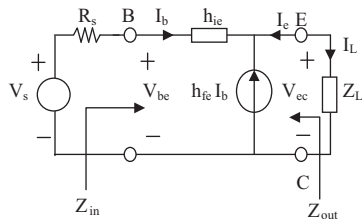


Fig. 7.19

Features:

1. Highest current gain ($1 + h_{fe}$).
2. Voltage gain is always less than unity (lowest).
3. Input and output currents are in phase.

4. Input and output voltages are in phase.
5. Input impedance is the highest of all the three configurations.
6. Output impedance is the lowest of the three configurations.
7. Used at a place where the impedance conversion from a high value to low value is desired. Therefore, it is always used as the last stage of any audio amplifier where its output impedance is matched to low impedance speaker to transfer maximum amount of power.
8. Since it has high input impedance therefore, it can be used as a buffer amplifier, which draws negligible current and does not load the previous stage.
9. Z_{in} depends upon the load.

Approximate values for different quantities using approximate equivalent model are given as follows:

Small Signal Model: At High Frequency

Hybrid π Model/Giacoletto model

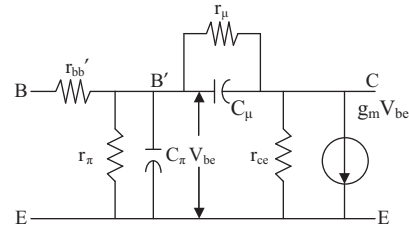


Fig. 7.20

$$r_{\pi} = [1/g_{be}]; r_{ce} = [1/g_{ce}]$$

$r_{bb'}$ = It has equivalent resistance due to base spreading resistance. Base region is very thin in transistor. Current which enters the base from emitter must flow through narrow path to reach the base terminal. The cross section area for current flow in collector or emitter is very much larger than in base.

r_{π}, C_{π} = equivalent resistance and capacitance due to forward biased junction.

$$r_{\pi} = 1 \text{ k ohm}, C_{\pi} = 100 \text{ pF},$$

as $C = \epsilon A/d, \quad \text{FB} \uparrow \rightarrow d \downarrow \rightarrow C \uparrow$

This represents the diffusion capacitance between base and emitter. This is due to excess of minority charge in base.

C_{μ}, r_{μ} = Equivalent resistance and capacitance due to reverse biased junction.

$$r_{\mu} = 4 \text{ M ohm}, C_{\mu} = 3 \text{ pF}, \text{RB} \uparrow \rightarrow d \uparrow \rightarrow C \downarrow.$$

Relation between Low Frequency and High Frequency Transistor Parametre

Transistor Tran conductance

$$g_m = (I_C / V_T)$$

$$g_m = (I_C / 26) \text{ where, } I_C \text{ is in milliampere}$$

Input conductance

$$g_{b'e} = (g_m / h_{fe})$$

$$r_{b'e} = (h_{fe} / g_m)$$

$r_{b'e}'$ is directly proportional to temperature and inversely proportional to current.

Feedback conductance $g_{b'c}$

$$g_{b'c} = h_{re} g_{b'e}$$

Base spreading resistance r_{bb}

$$r_{bb'} = h_{ie} - r_{b'e}$$

$$h_{ie} = h_{fe} V_T / |I_C|$$

Output conductance g_{ce}

$$g_{ce} = h_{oe} - g_m h_{re}$$

Dependence of parametre upon current, voltage, and temperature

Variation with Increasing

Parametres	I_C	$ V_{CE} $	T
g_m	$ I_C $	(No relation)	$\frac{1}{T_s}$
r_{bb}'	Decreases	Increases	Increases
r_{be}'	$\frac{1}{ I_C }$	Increases	Increases
C_e	$ I_C $	Decreases	(No relation)
C_c	Independent	Decreases	Independent
h_{fe}	--	Increase	Increases
h_{ie}	$\frac{1}{ I_C }$	Increase	Increases

Short Circuit Current Gain

$$A_I = \frac{I_L}{I_i} = \frac{-h_{fe}}{1 + j[f/f_\beta]}; f_\beta = \frac{1}{2\pi r_\pi (C_\pi + C_\mu)}$$

where, f_β is the bandwidth of amplifier
= half power frequency.

Figure of Merit (f_T)

It is the frequency at which the short circuit current gain become unity.

$$A_I = \frac{I_L}{I_i} = \frac{-h_{fe}}{1 + j[f/f_\beta]}$$

$$\text{At } f = f_\beta; A_I = 1$$

$$f_T = h_{fe} * f_\beta = \frac{h_{fe}}{2\pi r_\pi (C_\pi + C_\mu)}$$

Miller's Theorem

It states that if an impedance Z is connected between the input and output terminal of network between which there is voltage gain A_v , the same effect can be held by removing Z and connecting an impedance Z_1 at the input and Z_2 at output.

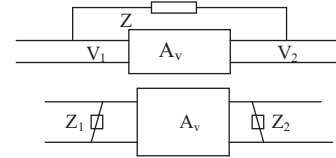


Fig. 7.21

$$Z_1 = \frac{Z}{1 - A_v}; \quad Z_2 = \frac{Z}{1 - \left(\frac{1}{A_v}\right)}$$

$$Y_1 = Y(1 - A_v); \quad Y_2 = [1 - (1/A_v)]$$

$$C_{in} = C(1 - A).$$

7.8 FET AMPLIFIER ANALYSIS

JFET Self-Bias Configuration

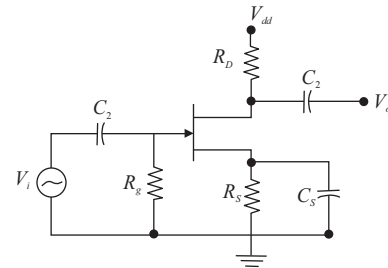


Fig. 7.22

Two cases arise:

(A) R_s bypass

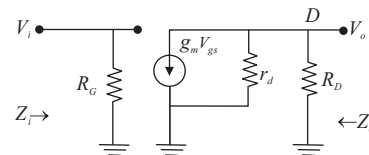


Fig. 7.23

7.10 ■ Analog Electronic Circuits

- (a) Input impedance $Z_i = R_G$
 (b) Output impedance $Z_o = (R_D \parallel r_d)$

$$Z_o \approx R_D \text{ if } (r_d \geq 10R_D)$$

- (c) Voltage gain

$$A_v = -g_m (R_D \parallel r_d)$$

$$A_v = -g_m R_D \text{ (if } r_d \geq 10R_D)$$

→ Phase shift of 180° exists between input and output.

JFET Voltage Divider Configuration

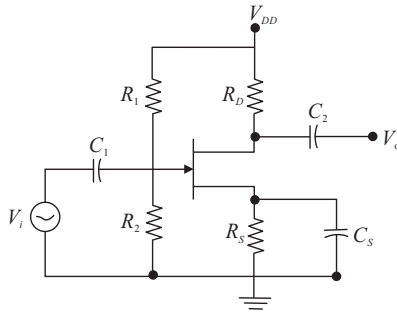


Fig. 7.24

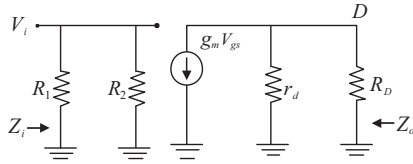


Fig. 7.25

1. Input impedance $Z_i = (R_1 \parallel R_2)$

2. Output impedance

$$Z_o = (r_d \parallel R_D)$$

$$Z_o \approx R_D \text{ if } (r_d \geq 10R_D)$$

3. Voltage gain

$$V_o = -g_m V_{gs} (r_d \parallel R_D)$$

$$V_o / V_{gs} = A_v = -g_m (r_d \parallel R_D)$$

$$-g_m R_D \text{ (if } r_d \geq 10R_D)$$

Voltage Gain at Low Frequencies

For CS-FET amplifier

$$Z_{in} = R_1 \parallel R_2 ;$$

$$Z_o = R_L$$

$$A_v = \frac{-\mu R_L}{r_d + R_L} = -g_m (r_d \parallel R_L)$$

For CD-FET amplifier or source follower

$$Z_{in} = R_G$$

$$Z_o = r_d \parallel R_L \parallel \frac{1}{g_m}$$

$$\cong R_L \parallel \frac{1}{g_m} \text{ (if } r_d \geq 10R_L)$$

$$A_v = \frac{\mu R_L}{r_d + (\mu + 1) R_L} = g_m \frac{r_d \parallel R_L}{1 + g_m (r_d \parallel R_L)}$$

Equivalent Circuit of FET at High Frequencies

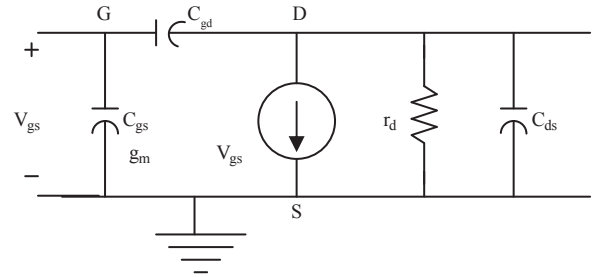


Fig. 7.26

Voltage Gain at High Frequencies

For CS-FET amplifier

$$A_v = \frac{-g_m + Y_{gd}}{Y_L + Y_{ds} + g_d + Y_{gd}}$$

$$C_{in} = C_{gs} + (1 - A_v) C_{gd}$$

For CD-FET amplifier or source follower

$$A_v = \frac{(g_m + j\omega C_{gs}) R_s}{(1 + g_m + g_d + j\omega C_T) R_s}$$

$$C_T = C_{gs} + C_{ds}$$

$$C_{in} = C_{gd} + (1 - A_v) C_{gs}$$

7.9 POWER AMPLIFIER (LARGE SIGNAL AMPLIFIER)

Power amplifiers are meant for large signal amplification. Power stage is normally the final stage of a cascade amplifier and driver. The energy conversion device i.e., speaker, antenna or transducer

etc. The power amplifier does not actually amplify the power, instead it takes power from the dc power supply connected to the power circuit and converts it into useful ac signal power. $Z_{in} \rightarrow$ high, $Z_{out} \rightarrow$ low, heat sinks are used.

Class A

Here, the dc bias is adjusted much less than its cut off value so that the output current flows for full input voltage cycle.

Class B

Here, the dc bias is adjusted equal to the cut off value so that the output current flows for half of the input voltage cycle. Hence the output dc component will always be equal to zero.

Class AB

Here, the dc bias is adjusted slightly less than is cutoff value so that the output current flows for more than half but less than input voltage cycle. This class of amplifier is just a compromise between class A and class B amplifier.

Features:

1. Output power is medium
2. Medium distortion
3. Medium efficiency
4. Used as modulating amplifier
5. Used with untuned power amplifier.

Class C

Here the dc bias is adjusted greater than its cutoff value so that the output current flows for less than half of the input voltage cycle.

Therefore, the output current will be in the form of pulses which will be highly rich in harmonic i.e., frequency multiplier.

Class D

This type of amplifier operation is used in pulse signal which are **on** for short interval and **off** for long interval.

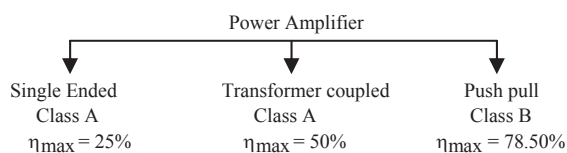


Fig. 7.27

7.10 SINGLE STAGE AMPLIFIER

Single Ended Class A Amplifier

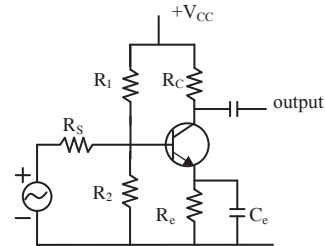


Fig. 7.28

$$\text{Thus maximum efficiency} = \frac{\left(\frac{V_{CC}^2}{8R_C}\right)}{\left(\frac{V_{CC}^2}{2R_C}\right)} \times 100 = 25\%$$

Class A Transformer Coupled Amplifier

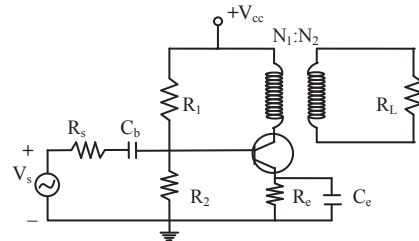


Fig. 7.29

Conversion efficiency (η)

$$= \frac{\text{Signal power delivered to load}}{\text{DC power supplied to output circuit}} \times 100 = 50\%$$

$$\left[\text{DC power supplied } (V_{CC} I_C) \right]$$

1. Efficiency is very low. This is because of the fact that a large amount of dc power is dissipated across the load.
2. The efficiency can be increased to 50% in transformer, where, R_L is effectively isolated from the power supply V_{CC} using the transformer coupling as shown in the figure 7.29.

Push-Pull Class B Amplifier

This type of amplifier is turned 'ON' when AC signal is applied. DC bias leaves the transistor biased just 'OFF'. To obtain output for the full cycle of signal, it is necessary to use two transistors and have each conduct on opposite half cycles. Push-pull

amplifier circuit. One part of circuit pulls the signal high during one half cycle and other part pulls the signal low during other half cycle.

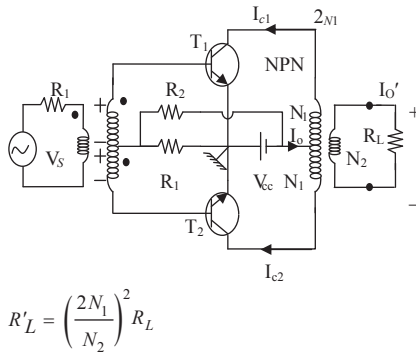


Fig. 7.30

$$\begin{aligned} \text{Output load current} &= k(i_{c1} - i_{c2}) \\ &= 2k(B_1 \cos \omega t + B_1 \cos 3\omega t + \dots) \end{aligned}$$

Only odd harmonics are present. The push-pull system has balanced out the even harmonics.

→ In class B operation, the operating point is at cutoff so that the signal is amplified by one transistor only for one half of the cycle,

$$\eta = \frac{P_{ac \text{ to load}}}{P_{dc}} = \frac{\pi}{4} \left(\frac{V_{cc} - V_{min}}{V_{cc}} \right) \times 100$$

theoretical $\max \eta = \eta_{\max} = \pi / 4 \times 100 = 78.5\%$

$$\text{also } \frac{P_{D \max}}{P_{ac \max}} = \frac{4}{\pi^2} = 0.4$$

Under these maximum values of P_{ac} , P_D per transistor $= 0.2P_{ac}$, $P_d \max = \frac{1}{5} P_{ac \max}$.

Maximum AC power obtainable in class B push-pull $= 5P_D$ (of the transistor).

Characteristics:

1. The even harmonic are absent at the output of a push-pull amplifier i.e.,
 $I_C = 2 I_1 \sin \omega t + 2 I_2 \sin 3\omega t + \dots$
2. The amplifier gives more output power per transistor for a given amount of distortion.
3. Less distortion is achieved for a given power output per transistor.
4. If quiescent current is low. Hence, the efficiency is maximum i.e., $25\pi = 78.5\%$

$$\eta = 25 \pi \left(1 - \frac{V_C(\min)}{V_{cc}} \right)$$

Distortion in the Output Caused by Many Factors:

1. If the transistors are not matched in push pull configuration.
2. Collector characteristic many be non-linear.
3. Input characteristic are non-linear.

Crossover Distortion

The input characteristic of transistor are such that no appreciable current flows until the emitter junction is forward biased by cut in voltage V_γ . Under these conditions, a sinusoidal base voltage excitation does not result in a sinusoidal output current.

To minimize cross over distortion, transistor must operate in class AB mode, where a small standing current flows in the case of zero excitation. The remedy is class AB push-pull amplifier.

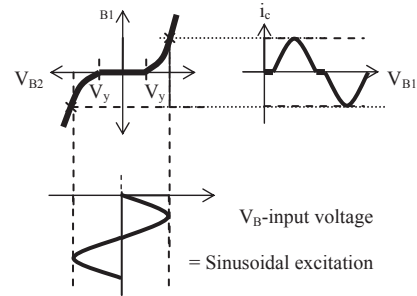


Fig. 7.31

Complementary-Symmetry Connection

In this case, two transistors, one NPN and the other PNP have their emitter connected together.

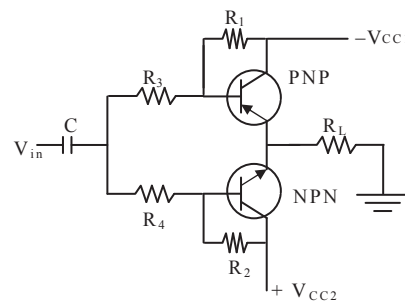


Fig. 7.32

- Bases are tied and signal is fed to the base.
- Both transistors are biased near cutoff.
- This is also known as push-pull and it doubles the dynamic range of the circuit by accommodating a larger input range of the circuit of accommodating a large input signal.

7.11 MULTISTAGE AMPLIFIER

CC-CC (Darlington Pair)

The CC amplifier has high input impedance as a single transistor; to increase the input impedance still further, we use the Darlington emitter follower, which is CC-CC amplifier. The two transistors form a composite pair. This can be considered single transistor with only three external leads.

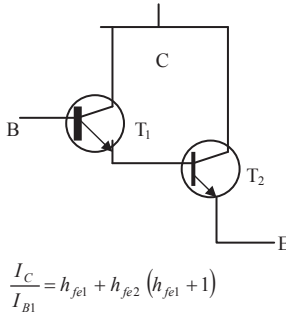


Fig. 7.33

Assuming two transistors have same h_{fe}

$$\frac{I_C}{I_{B1}} = h_{fe} \times h_{fe} = h_{fe}^2; \quad A_v \cong 1.$$

Input Impedance

$$R_i = h_{ie1} + (h_{fe1} + 1) h_{ie2}$$

$$R_i = 2h_{ie2} (h_{fe1} + 1)$$

assuming $h_{ie1} = h_{ie2} = h_{ie}$

Cascaded BJT Stages

- Gain of one stage of amplifier may not be sufficient to obtain the required gain and also the required gain may be worked out in a single stage, the operating condition of the transistors may be impracticable.
- Overall gain is the product of gain of individual stages.
- $A_{VT} = A_{V1} \times A_{V2}$.

Cascode Connection

This CE-CB connection

- Common emitter stage drives a common base amplifier.
- Gain can be improved by using large value of R_L over a wide range of frequencies.

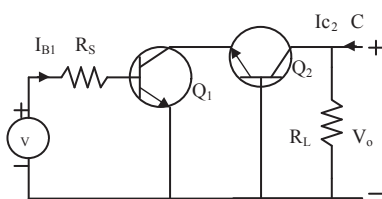


Fig. 7.34

- Overall current gain $A_i = \frac{I_{C2}}{I_{B1}} = \beta_0$.

- Voltage gain $A_v = \frac{-\beta_0 R_L}{(R_s + r_{be})}$.

- Output resistance of a CB stage is high, so we can connect a large load resistance R_L .
- This input resistance for the CB stage is low and this is the load resistance for the CE stage. The low input resistance of CB stage makes Q_1 operate into a short-circuit load, so voltage gain of common emitters stage is low. This cause reduces the input capacitances so its bandwidth gets increased.
- It is used in *wide band amplifiers* due to its large bandwidth.

COMPOUND CONFIGURATION

Cascade FET connection

Input impedance $Z_i = R_{g1}$

Output impedance $Z_o = R_{d2}$

$$\begin{aligned} \text{Overall gain } A_v &= V_{O3} / V_{i1} \\ &= (V_{O3} / V_{i3}) \times (V_{O2} / V_{i2}) \times (V_{O1} / V_{i1}) \\ &= A_{v3} \cdot A_{v2} \cdot A_{v1} \end{aligned}$$

Gain in dB $20 \log_{10} A_v = A_{v3} + A_{v2} + A_{v1}$ in dB

CE-CE with RC coupled

Provides high voltage gain overall analysis leads to

$$R_i = R_{i1}$$

$$R_o = R_{o2}$$

$$A_v = A_{v1} \cdot A_{v2}$$

$$A_i = A_{i1} \cdot A_{i2}$$

CE-CB(cascode amplifier)/unilateral voltage amplifier

CE-CC (Voltage amplifier with impedance matching)

This is very low frequency signal amplification.

CC-CC (Darlington Amplifier)

High input impedance amplifier

Input impedance $R_{i1} \approx h_{fe}^2 R_e$

Bandwidth

In case of multistage amplifier, all of which are identical.

Overall lower cutoff frequency

$$f_1(n) = f_1 / \sqrt{2^n - 1}$$

Overall upper cutoff frequency

$$f_2(n) = f_1 / \sqrt{2^n - 1}$$

7.12 DIFFERENTIAL AMPLIFIER

It is the basic building block of the operational amplifier:

- The first stage of an op-amp is Differential Amplifier (DA).
- DA consists of two transistors which are emitter coupled and whose characteristics are identical.

There are two types of input signal to the DA:

Differential mode: $V_d = V_1 - V_2$

Common mode: It is the average between the input voltage V_2 and V_1

$$V_c = \frac{V_1 + V_2}{2}$$

High Frequency Analysis

$$A_{DM} = \frac{-h_{fe} \cdot R_L}{R_s + r_{b'b} + r_{b'e}} = \frac{-h_{fe} \cdot R_L}{r_{b'e}} = -g_m R_L$$

$$A_{CM} = \frac{-g_m \cdot R_L}{1 + 2 g_m R_E}$$

Low Frequency Analysis

$$A_{DM} = \frac{-h_{fe} \cdot R_L}{R_s + r_{b'b} + r_{b'e}}$$

$$A_{CM} = \frac{-g_m \cdot R_L}{1 + 2 g_m R_E}$$

where, A_{DM} and A_{CM} are known as differential mode gain and common mode gain.

Common Mode Rejection Ratio (CMRR)

- $CMRR = 1 + 2g_m R_E \approx 2g_m R_E$
- For large value of CMRR, we need large value of R_E , so use current sources having high output resistance for FET based differential amplifiers.

$$CMRR = \frac{1 + 2 R_s \mu}{r_d} \approx 2g_m R_s$$

7.13 OPERATIONAL AMPLIFIER

Operational Amplifier

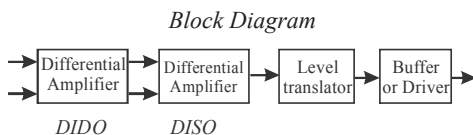


Fig. 7.35

Differential Amplifier (Dual Input Dual Output)

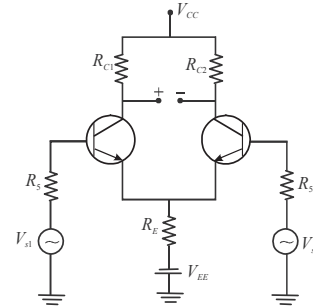


Fig. 7.36

R_E is used to get high input impedance

V_{EE} is used for biasing.

Note:

- Almost all IC's are made up of direct coupled amplifier without biasing resistors and with capacitors in order to decrease the space required.
- For AC

$$R_i = h_{ie} + (1 + h_{fe})2R_e$$

Thus, R_i is more.

R_E makes common mode gain small to increase CMRR.

Differential Amplifier (Dual in Single Out)

The differential amplifier is to increase internal gain of operational amplifier.

Note: If using FET in Differential amplifier internal gain is very small internally, op-amp needs only single supply.

Level Translator

It is a clamper used to reduce the DC level. Since direct coupled amplifier also amplifies DC, we must use level translator. Level translator is a **clamper circuit**.

Buffer or Driver

It is used to increase the output current and to provide matching.

Difference gain

$$A_d = V_o / (V_2 - V_1)$$

Common Mode Gain

$$A_c = (V_o / V_c)$$

Where, $V_c = ((V_1 + V_2) / 2)$

Total output $V_o = (A_d V_d + A_c V_c)$

Common mode rejection ratio (ρ) = (A_d / A_c)

Universal model

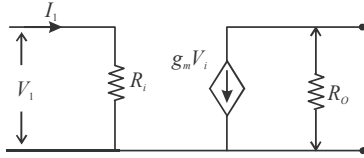


Fig. 7.37

For BJT	For BJT	For BJT
$R_i = h_{ie}$	$R_i = \infty$	$R_i = \infty$
$G_m V_i = h_{ie} i_b$	$G_m V_i = g_m V_{gs}$	$G_m V_i = g_m V_i$
$R_o = \infty$	$R_o = r_d$	$R_o = r_d$

Differential gain (in terms of h_{fe})

$$A_d = \frac{1}{2} \{-h_{fe} \cdot R_C / h_{ie} + R_s\} \text{ (without } R_E)$$

If R_E is present the gain

$$A_d = \frac{1}{2} \left[-h_{fe} \cdot R_C / \{h_{ie} + R_s + (1 + h_{fe})2R_E\} \right]$$

Parameters for Operational Amplifier

1. Open loop voltage gain $A_v \rightarrow \infty$
2. Input impedance $Z_{in} \rightarrow \infty$
3. Output impedance $Z_{out} \rightarrow 0$
4. Common mode rejection ratio $CMRR \rightarrow \infty$
5. Slow rate = $dV_o / dt \big|_{\max}$

Slow Rate

It is defined as the maximum time rate of change of the output voltage $(\delta v_o / \delta t)_{\max}$.

Describes the large signal limitation of the op-amp.

For faithful reproduction of this sinusoid requires

$$\omega V_m \leq \text{slow rate}$$

where, V_m = peak amplitude of applied signal

ω = frequency of input signal.

6. Fuller Bandwidth $f_m = (\text{slow rate} / 2\pi V_m)$

Where, (V_m) is input peak voltage)

7. Characteristics do not drift with temperature.

Transfer characteristics

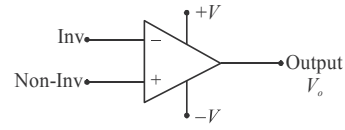


Fig. 7.38

7.14 FEEDBACK AMPLIFIER

Feedback is the process whereby a portion of the output is returned to the input to form part of the system excitation.

Feedback was used to make the operating point of a transistor insensitive to both manufacturing variation in β_i and temperature.

Feedback Amplifier Topologies

There are four basic types:

1. Shunt-Shunt
2. Shunt-Series
3. Series-Shunt
4. Series-Series.

These designations correspond to the input and output port connections respectively between the feedback network and the basic amplifier.

Gain with feedback

$$A_f = \frac{X_o}{X_s} = \frac{A}{1 - \beta \cdot A}$$

where, A = transfer function without feedback.

If $|A_f| < |A|$, the feedback is termed as negative.

And if $|A_f| > |A|$, the feedback is termed as positive.

Fundamental Assumption

Three conditions are implicit in the representation of the ideal feedback amplifier:

1. The input signal is transmitted to the output through the amplifier A and not through the feedback network β . Means feedback network is unilateral.

- The feedback signal is transmitted from output to input through the feedback network only.
- The transfer ratio β is independent of source and load resistance.

Properties of Negative-Feedback Amplifiers

Although negative feedback results in reduced gain, it is used because of following reasons:

- Bandwidth get increased
- Effect of noise get reduced
- Distortion get reduced.

Input Impedance in Feedback Amplifier Input Resistance

If the feedback signal is returned to the input in series with the applied voltage, the input impedance gets increased.

$$R_{if} = R_i (1 - \beta A)$$

where, R_{if} = Input resistance after feedback.

R_i = Input resistance without feedback.

- For negative feedback V_f is 180° out of phase with V_s , V_i is less than it would be if V_f were absent. Hence, $I = V_i/R_i$ decreased.
Causes the ratio V_s/I to increase.
- If shunt connection is used at the input of a negative feedback amplifier, the impedance decreases.

$$R_{if} = \frac{R_i}{(1 - \beta \cdot A)}$$

Output Impedance

When the output of a feedback employs a shunt connection, negative feedback reduces the output resistance:

$$R_{of} = \frac{R_o}{(1 - \beta \cdot A)}$$

Output impedances are increased when a negative feedback amplifier employs a series connected output. $R_{of} = R_o (1 - \beta A)$.

Effect of feedback on Bandwidth

$$\text{Open loop gain } A_{OL} = \frac{A_o}{1 + \left(\frac{s}{\omega_n} \right)}$$

(without feedback)

Return Ratio

$$T(s) = \frac{T_o}{1 + \left(\frac{s}{\omega_n} \right)}$$

where, A_o and T_o are the midband value of A_{OL} and $T(s)$, ω_n is angular frequency of the dominant pole.

$$A(s) = \frac{A_{OL}}{1 + A_{OL} \cdot T(s)} = \frac{A_{FO}}{1 + \left(\frac{s}{\omega_n} \right)}$$

$$\text{where, } A_{FO} = \frac{A}{(1 + T_o)}$$

$$\omega_H = (1 + T_o) \omega_n$$

Negative feedback has increased the bandwidth by a factor $(1 + T_o)$, the same factor by which A_{OL} is reduced.

Stability

In the design of a feedback amplifier, it must be ascertained that the circuit is stable at all frequencies.

A system is stable only if all bounded input signals produce bounded output signals.

- If a pole of transfer function exists with a positive real part, this causes output to increase exponentially with time, and hence unbounded.

Stability of Feedback Amplifiers

$$A_F(s) = \frac{A_{OL}(s)}{1 + T(s)}$$

Amplifier without feedback is stable if all the poles of AOL lie in the left half of s-plane.

Amplifier with feedback is stable if all the zeros of T (s) lie in the left half of s-plane.

Effect of negative feedback on amplifier characteristics.

Type of feedback

	Voltage series	Current series	Current shunt	Voltage shunt
Z_{out}	Decrease	Increases	Increases	Decreases
Z_{in}	Increases	Increases	Decreases	Decreases
Improves Characteristics of	Voltage Amplifier	Transconductance amplifier	Current amplifier	Trans-Resistance amplifier
Desensitizes	A_{vf}	G_{Mf}	A_{If}	R_{Mf}

Classification and Representation of Amplifiers

- Voltage Amplifier or Voltage Series Amplifier

$$R_i \gg R_s; R_o \ll R_L$$

R_i = Input resistance of the amplifier.

This circuit provides an output voltage proportional to the input voltage. $R_i \gg R_s$ and $R_o \ll R_L$.

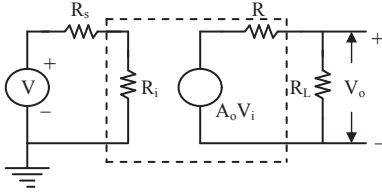


Fig. 7.39

2. The Current Amplifier or Current Shunt Amplifier

An ideal current-controlled source has zero input resistance R_i and has infinite output resistance R_o .

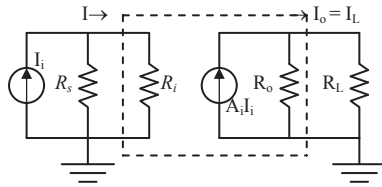


Fig. 7.40

$|R_i| \ll R_s$ and $|R_o| \gg R_L$; $I_o = A_i I_i$
Output current is proportional to input current.

3. The Voltage-Current Converter or Trans-conductance Amplifier (Voltage Controlled Current Source) or Current Series Amplifier

4.

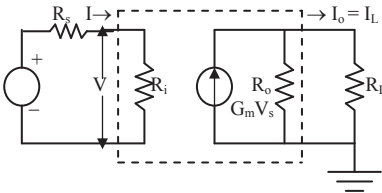


Fig. 7.41

This ideal voltage – controlled current source.

$|R_i| \gg R_s$ and $|R_o| \gg R_L$
 $I_o = G_m V_s$.

5. Current-Voltage Converter or Trans-Impedance Amplifier or Voltage Shunt Amplifier (Current Controlled Voltage Source)

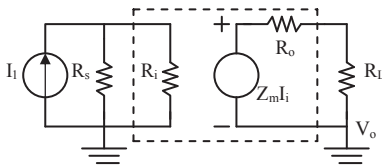


Fig. 7.42

This is ideal current controlled voltage source.

$R_i \ll R_s$ and $|R_o| \ll R_L$
 $V_o = Z_m I_i$.

7.15 FREQUENCY RESPONSE

When a multi frequency signal extending from very low frequency to very high frequency is applied to an amplifier, it should amplify all the signals in the range uniformly. This is known as frequency response. In practice, it is not so because the amplifier is constructed out as frequency sensitive element like condenser, which causes attenuation of the signals.

Amplifier may be capable of uniform amplification from low frequency F_L to a high frequency F_H and the range $(F_H - f_L)$ called *bandwidth*.

Rise Time

The response of amplifier is studied by feeding a step signal.

$$t_r = \frac{2.2}{\omega_h}; \quad t_r = \frac{0.35}{f_h}$$

where, t_r = rise time (time required from 10% to 90%)
 f_h = higher cutoff frequency.

Frequency Response of Cascaded Stages

For n identical stages:

1. The upper cutoff frequency decreases

$$f_H = f_{H1} \sqrt{2^{1/n} - 1}.$$

2. The lower cutoff frequency increase

$$f_L = \frac{f_{L1}}{\sqrt{2^{1/n} - 1}}.$$

3. Overall bandwidth decreases.
4. The gain bandwidth product remain constant.
5. The Transmission line parametre are used, i.e., A, B, C, D .

7.16 SIMPLE OPS-AMPLIFIER APPLICATION CIRCUIT

Inverting Amplifier

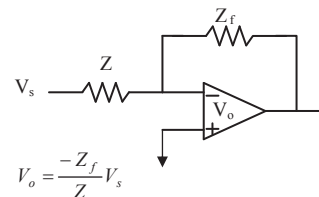


Fig. 7.43

The input resistance is equal to resistance Z .

Non-Inverting with Potential Divider

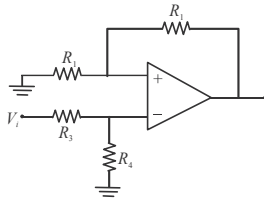


Fig. 7.44

$$V_o / V_i = (R_1 + R_2 / R_1) \times (R_4 / R_3 + R_4)$$

Unity Follower

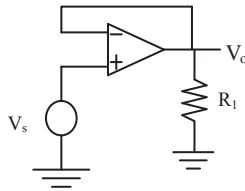


Fig. 7.45

The output signal is in phase with the input signal and of the same magnitude.

Input impedance is very high, so it provides very good isolation between stages.

Summing Amplifier

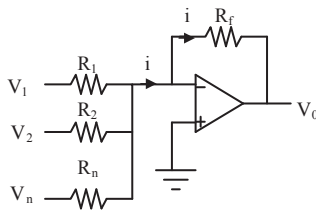


Fig. 7.46

$$V_o = - \left(\frac{R_f V_1}{R_1} + \frac{R_f V_2}{R_2} + \frac{R_f V_n}{R_n} \right)$$

Differential Amplifier

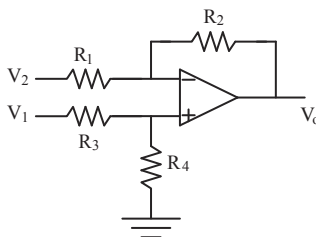


Fig. 7.47

$$\text{If } \frac{R_2}{R_1} = \frac{R_4}{R_3}$$

$$V_o = \frac{R_2}{R_1} [V_1 - V_2]$$

Differentiator

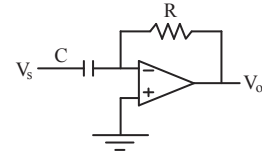


Fig. 7.48

$$\frac{V_o(s)}{V_s(s)} = -sRC$$

$$V_o = -j\omega RCV_i$$

$$(V_o / V_i) = \omega RC$$

Differentiator acts as a high pass filter.

Disadvantage of using differentiator is that for high frequency, capacitive impedance reduces and capacitor acts as short circuit, thus noise gets amplified.

Practical Circuit

$$V_o / V_i = -Z_2 / Z_1 = -R_2 / (R_1 + j\omega C)$$

$$V_o / V_i = -(R_2 / R_1) / (1 + j2\pi C_1 R_1)$$

$$H(f) = H_o(f) / (1 + j(f_1 / f))$$

$$R_1 C_1 \ll T$$

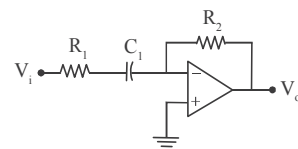


Fig. 7.49

Note: Generally, integrator is preferred over differentiator. This is due to small R and C which costs less and gain is also high.

Integrator

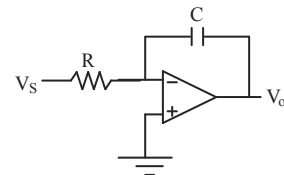


Fig. 7.50

$$\frac{V_o(s)}{V_s(s)} = -\frac{1}{sRC}$$

$$V_o = \frac{-1}{RC} \int V_i dt$$

Practical Circuit

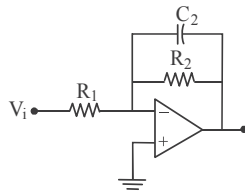


Fig. 7.51

$$V_o = -1/R_1 C_2 \int V_i dt$$

Integrator acts as a low pass filter

Non-Inverting Integrator

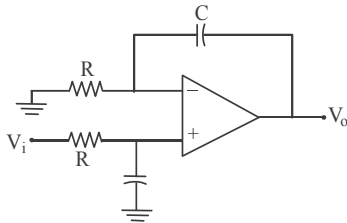


Fig. 7.52

$$V_i / (R + 1/j\omega C) * (1/j\omega C) = V_o / (1/j\omega C + R)$$

$$V_i = V_o (Rj\omega C)$$

$$V_o = \frac{V_i}{(j\omega RC)}$$

$$V_o = 1/RC \int V_i dt$$

This is a small non-inverting integrator

Precision Rectifier

Main defect with Si rectifier is its cut in voltage of 0.7 V and so, voltages less than this value cannot be rectified. This defect has overcome in op-amp rectifiers and voltages in the mill volt range can be obtained.

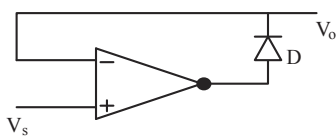


Fig. 7.53

When V_s is +ve diode is ON and feedback loop is established and V_o follows V_s .

When V_s is -ve, diode is OFF and feedback loop is open and $V_o = 0$.

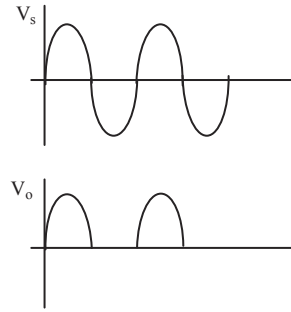


Fig. 7.54

Non-Inverting Integration

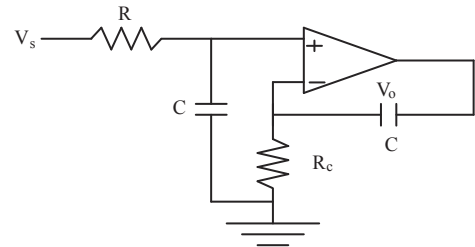


Fig. 7.55

$$V_o = \frac{1}{RC} \int V_s dt.$$

Double Integration

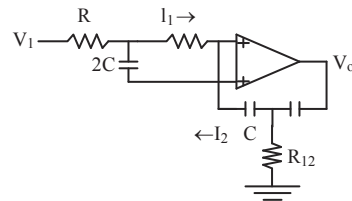


Fig. 7.56

$$\frac{V_o}{V_s} = -\frac{1}{(sRC)^2}.$$

Logarithmic Amplifiers

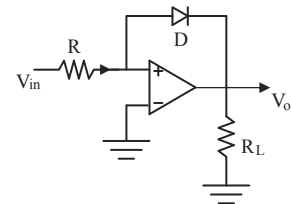


Fig. 7.57

When $V_{in} < 0$; diode is off, Op-amp behaves as comparator. At this time

$$V_o = +V_{sat}$$

- When $V_{in} > 0$ diode is ON
 $V_o = -0.7 \text{ V}$
- For small range of V_{in} , It behaves as logarithmic amplifier.

$$V_o = 2.3 \frac{KT}{q} \log_{10} \left(\frac{V_{in}}{R_L I_o} \right)$$

Antilogarithmic Amplifier

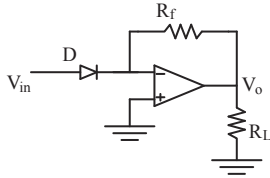


Fig. 7.58

$$V_o = -R_f \cdot I_o \ln^{-1} \left(\frac{V_{in}}{nV_T} \right)$$

7.17 FILTER

All Pass Filter

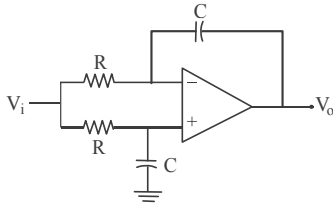


Fig. 7.59

$$(V_o / V_i) = \frac{(1 - j\omega RC)}{(1 + j\omega RC)}$$

$$|V_o / V_i| = 1$$

$$\text{Phase shift} = -2 \tan^{-1} (\omega RC).$$

Band Pass Filter

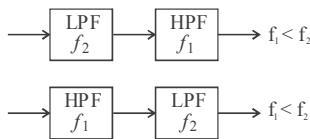


Fig. 7.60

- If $f_1 = f_2$ single frequency pass filter
- If $f_1 > f_2$ all stop filter

Circuit Diagram

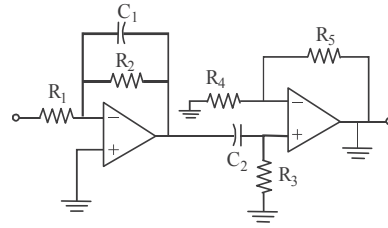


Fig. 7.61

$$\begin{aligned} \frac{V_o}{V_i} &= \frac{\{-(R_2/R_1)(R_4 + R_5)/R_4\}}{\{(1 + j2\pi fR_2C_1)(1 - j/2\pi fR_2C_1)\}} \\ &= \frac{H_0}{\{(1 + jf/f_2)(1 - jf_1/f)\}} \end{aligned}$$

Band Pass Filter Circuit Diagram

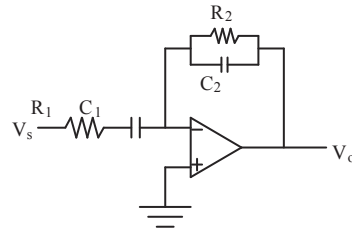


Fig. 7.62

$$\frac{V_o}{V_s} = \frac{-sC_1R_2}{(1 + sC_2R_2)(1 + sC_1R_1)}$$

Check Type of Filter

Putting $\omega = 0$ (capacitor open-circuit) and
 $\omega = \infty$ (capacitor short-circuit)

In above circuit, when $\omega = 0$, C_1 = open circuit and $V_o = 0 \text{ V}$, similar for $\omega = \infty$ ($C_1 = C_2$) so it does not pass high as well as low frequency so it is band pass.

Band Elimination Filter

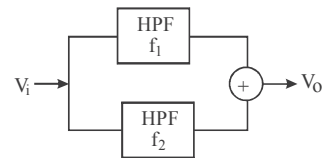


Fig. 7.63

Note:

1. $f_1 = f_2$ makes Notch filter
2. $f_1 > f_2$ all pass filter

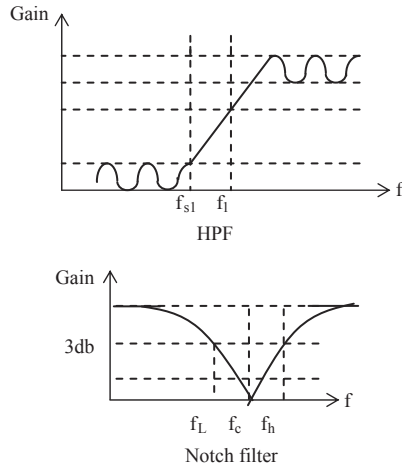


Fig. 7.64

Characteristic and Terminology

dB/decade When the frequency is increased by factor of 10, the amplitude or gain roll off at the rate of same dB.

Octave Frequency has doubled.

Logarithmic Scale

1. On a log scale horizontal axis each decade (factor of 10) increases or decreases, moves the same distance along the scale.
2. Starting point is never zero, if we go further left, each increment lowers the scale by 10 (i.e., 0.1, 0.01) but never reaches zero.

All Pole Filter

The most common LPFs have transfer functions that are in the ratio of a constant to a polynomial. These are called “all pole” filters.

1. All its poles are finite and at zero are infinite.
2. In general, an n th-order low pass all pole has a transfer function of the form

$$H(s) = \frac{H_0 a_0}{s^n + a_{n-1} s^{n-1} + \dots + a_1 s + a_0}$$

where, H_0 is gain of LPF which is defined as that value of transform function at $s = 0$ and the coefficients $a_0, a_1, \dots, a_{n-1}$ depend on the filter type.

Butter Worth Filter or Maximally Flat LPF

This is a filter which provide flattest pass band response and whose magnitude in the n th-order case is defined by

$$H(j\omega) = \frac{H_0}{\sqrt{1 + \left(\frac{\omega}{\omega_0}\right)^{2n}}} \text{ where, } H_0 \dots \text{ is the gain}$$

$\omega_0 \dots$ is the cutoff frequency

$n \dots$ is the number of order or poles

For $H_0 = 1$,

$n = 1, 2, 4, \dots, 6, \dots$ the response is

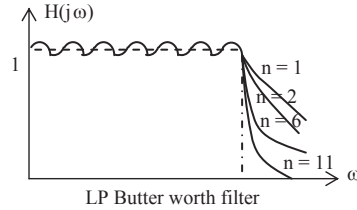


Fig. 7.65

First Order Active Low Pass Filter

1. It consists of a single Rc network and has a roll-off rate of 20 dB/decade. At original frequency, the phase shift 45° .
2. The denominator of transfer function has S .
3. It matches the response of the simple passive filter.
4. Passive filter is converted to an active filter by connecting its output to a non-inverting amplifier. For a gain of [10 dB] the passive filter is converted to a voltage follower. For this filter, the OP-AMPS main purpose is to drive the load [providing the low output impedance and minimizing the effect of the load impedance on the filter characteristics].

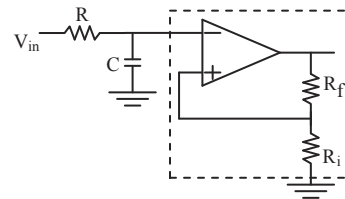


Fig. 7.66

$$A_o = 1 + \frac{R_f}{R_i}, \text{ Gain} > 1.$$

7.18 OSCILLATORS

The Barkhausen Criterion

The condition for sinusoidal oscillation can be expressed as:

$$T(j\omega_0) = 1$$

$$\angle T(j\omega) = -180^\circ$$

1. Two conditions must be satisfied by a circuit to sustain oscillation.
2. The phase shift through the amplifier; and feedback network must be 360° as T includes a minus sign which is equivalent to 180° of phase shift.

3. The magnitude of the gain of the amplifier and feedback network must be unity.
 $T(j\omega) = -1$ known as Barkhausen Criterion.
- Barkhausen Criterion is equivalent to stating that both the phase margin and gain margin are zero. So the phase and gain, crossover frequencies are equal.
 - In every practical oscillator the loop gain is slightly larger than unity and the amplitude of the oscillations is limited by the on-set of non-linearity.

OPS-AMP Version of PSO

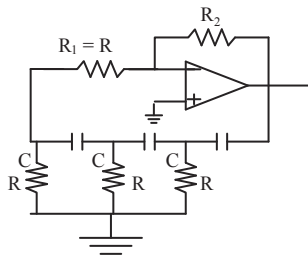


Fig. 7.67

- The oscillation, frequency is same as that of FET, PSO.
- OPS-amp gain $A_v = [-R_2/R_1]$ must be greater than 29.

BJT Phase Shift Oscillator

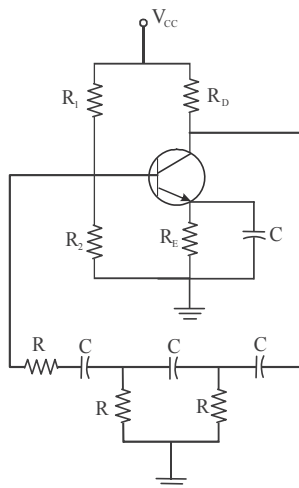


Fig. 7.68

Frequency of oscillator

$$f = 1 / 2\pi R_C \times 1 / \sqrt{(6 + 4R_C / R)}$$

$$h_{fe} > 23 + 29R / R_C + 4R_C / R$$

Minimum h_{fe} is 44.5 with R_C / R equal to 2.7

Wien Bridge Oscillator

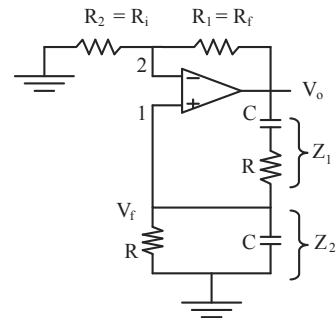


Fig. 7.69

$$R_f \rightarrow \text{Thermistor}; \frac{R_f}{R_i} \geq 2$$

$$A_v \geq 3; f_o = [1/(2\pi RC)]$$

Resonant Circuit Oscillator

Block Diagram

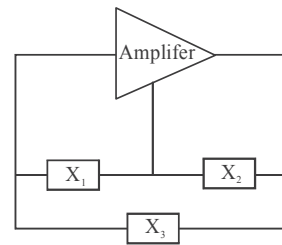


Fig. 7.70

Condition is $X_3 = -(X_1 + X_2)$

If X_1 and X_2 inductive then X_3 capacitive

If X_1 and X_2 capacitive then X_3 is inductive

Depending on the reluctance element, this can work as different type of oscillator,

Oscillator type	X_1	X_2	X_3
Colpitts Oscillator	C	C	L
Hartley Oscillator	L	L	C
Tuned input, Tuned output	LC	LC	

Frequency of oscillation is given by

For Hartely oscillator

$$f_o = \frac{1}{2\pi \sqrt{(L_1 + L_2) C_2}}$$

For Colpitt's oscillator

$$f_o = \frac{1}{2\pi \sqrt{\frac{C_1 C_2}{C_1 + C_2}} L_3}$$

For Clapp oscillator

$$f_o = \frac{1}{2\pi \sqrt{L_3 C_3}}$$

For Wein bridge oscillator

$$f_o = \frac{1}{2\pi RC}$$

$$|A_v| > +3$$

For RC-Phase shift oscillator

$$f = \frac{1}{2\pi\sqrt{6} RC} = \frac{1}{2\pi RC\sqrt{6}}$$

$$|A_v| > 29.$$

7.19 FUNCTION GENERATORS

Multivibrator

Op-amp can function as a multivibrator if positive feedback is given.

(a) Astable Multivibrator

Circuit Diagram

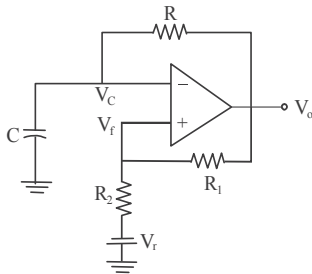


Fig. 7.71

Assume $V_{reference} = 0$ Volts

$$V_f = V_o \times \left(\frac{R_2}{R_1 + R_2} \right) = \beta_o V_o$$

If $V_c > V_f$ then $V_o = -V_{sat}$ capacitor discharge

If $V_c < V_f$ then $V_o = +V_{sat}$ capacitor charge

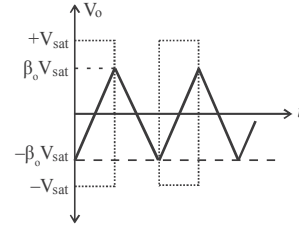


Fig. 7.72

In steady state, capacitor will charge from $-\beta_o V_{sat}$ to $+\beta_o V_{sat}$

(b) Monostable Multivibrator

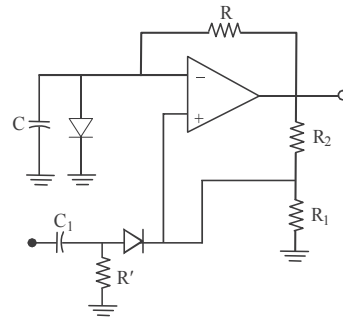


Fig. 7.73

Waveforms

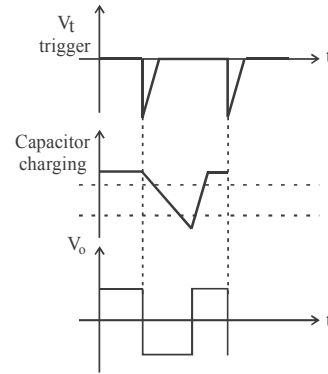


Fig. 7.74

(c) Triangular Wave Generator

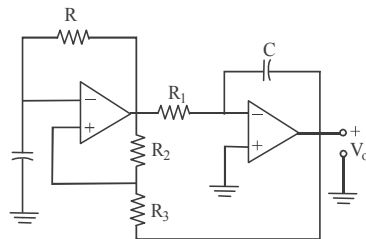


Fig. 7.75

Astable multi-vibrator followed by integrator can act as a triangular wave generator.

Circuit diagram 2

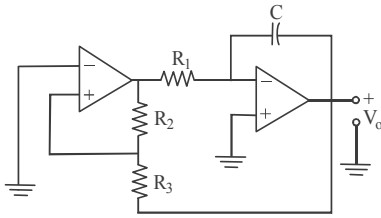


Fig. 7.76

Time period of this particular circuit diagram giving triangular wave is $(T = 4R_2R_1C / R_3)$.

7.20 IC 555 TIMER

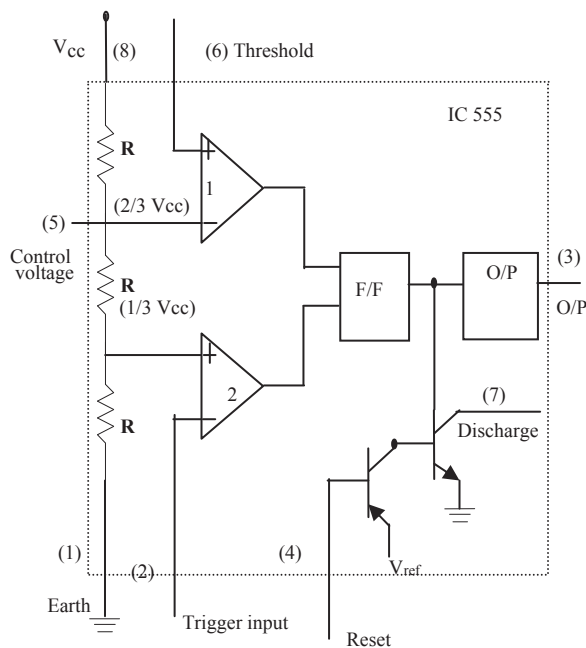


Fig. 7.77

Description of Pins

1. Ground
2. Trigger: It is required for monostable operation, whereas for astable operation 2 and 6 are shortened.
3. Output: Output of S-R Flip-flop. $S = R = 1$ Must be avoided if SR FF is used.
4. Reset: To reset the timer by using external input. In most cases 4 and 8 are shorted to give reset.
5. Control voltage: This is provided to control the charging level of capacitor and to avoid noise. This is generally

connected by a bypass capacitor for noise. Noise is high frequency. The bypass capacitor generally in μ Farad range.

6. Threshold: Voltage at this pin is compared with voltage at pin no. 5

$$V_o > V_s \text{ if } Q = 0 \quad \bar{Q} = 1$$

Then capacitor connected to pin 6 will discharge through internal transistor.

7. Discharge pin

Note: Depending on the resistor connected between 7 and 6 we get different waveform.

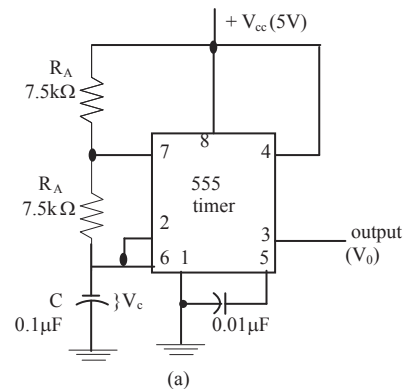
If Zero resistance $\rightarrow$ saw tooth waveform

If Finite resistance $\rightarrow$ triangular waveform

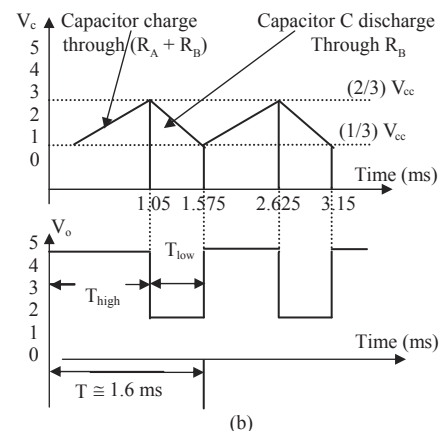
Timer is also called window comparator.

Astable Operation

One popular application of the 555 timer IC is an astable multivibrator or clock circuit. The following analysis of the operation of the 555 as an astable circuit includes details of the different parts of the unit and how the various inputs and outputs are utilized. Figure shows an astable circuit built using an external resistor and capacitor to set the timing interval of the output signal.



(a)



(b)

Fig. 7.78 Astable multivibrator: (a) Circuit (b) Waveforms

$$T_{\text{high}} \approx 0.7(R_A + R_B)C ; T_{\text{low}} \approx 0.7R_B C$$

The total period is, $T = \text{period} = T_{\text{high}} + T_{\text{low}}$

The frequency of the astable circuit is then calculated using *

$$f = \frac{1}{T} \approx \frac{1.44}{(R_A + 2R_B)C}$$

Since $T_{\text{ON}} \neq T_{\text{OFF}}$ asymmetrical square wave.

Note:

1. If diode is used to bypass R_2

$$T_{\text{ON}} = R_1 C \ln 2$$

$$T_{\text{OFF}} = R_2 C \ln 2$$

And if $R_1 = R_2$ then symmetrical square wave

2. If $R_2 = 0\Omega$

Then $T_{\text{OFF}} = \text{zero}$

Thus saw tooth/sweep wave will be output at V_C .

Using a Current source

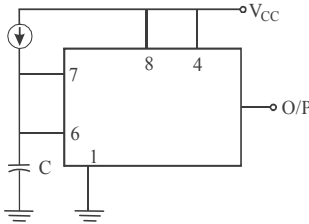


Fig. 7.79

$$V_C = 1/C \int I dt$$

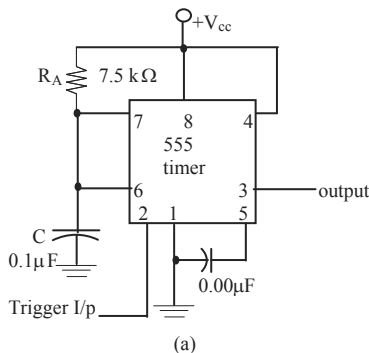
$$V_C = (I / C) t$$

This is a better sweep generator.

Monostable Operation

The 555 timer can also be used as a one-shot or monostable multivibrator circuit. When the trigger input signal goes negative, it triggers the one shot, with output at pin 3 then going high for a time period.

$$T_{\text{high}} = 1.1R_A C$$



(a)

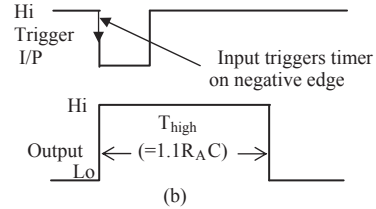


Fig. 7.80 Operation of 555 timer as one shot: it

Using the components value output waveform for the circuit of the figure above when triggered by a negative pulse.

$$T_{\text{high}} = 1.1R_A C = 1.1(7.5 \times 10^3)(0.1 \times 10^{-6}) = 0.825 \text{ ms}$$

Monostable Mode

1. Only one stable state. Thus trigger is required.
2. For pulse width modulation this can be used. Put message signal $m(t)$ at pin no.

7.21 POWER SUPPLY

Full Wave Rectifier

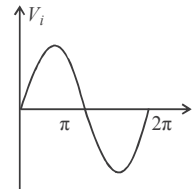
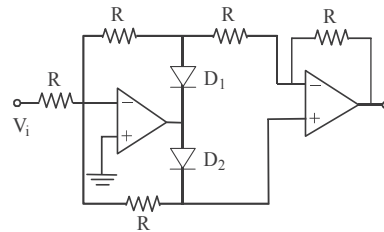


Fig. 7.81 Operation of 555 timer as one shot. (a) Circuit (b) Waveform

- (a) for $0 - \pi$
 $D_1 \rightarrow \text{ON}$
 $D_2 \rightarrow \text{OFF}$

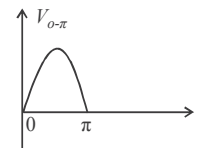


Fig. 7.82

- (b) For $\pi - 2\pi$
 $D_1 \rightarrow \text{OFF}$
 $D_2 \rightarrow \text{ON}$

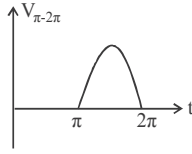


Fig. 7.83

Final output

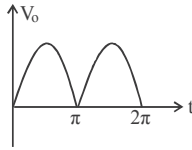


Fig. 7.84

$$V_d = \eta V_T \ln \left[1 + \frac{I}{I_o} \right]$$

$$V_d = \eta V_T \ln \left[1 + \frac{V_i}{RI_o} \right]$$

We get antilog amplifier if R and diodes are interchanged.

Filter

Shunt capacitor filter

When rectifier is FW replace 2π by π as now time period $= \pi$ and ripple factor

$$r = \frac{2\pi - \theta_c}{2\sqrt{3}R_L C}$$

Series inductor filter

$$r = \frac{2}{3\sqrt{2}} \frac{R_L}{\sqrt{R_L^2 + X_L^2}}$$

$X_L = \omega L$ for HWR and $X_L = 2\omega L$ for FWR.

LC Filter

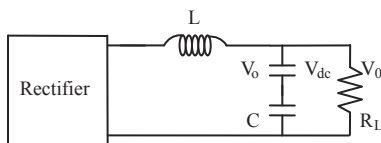


Fig. 7.85

$$r = \frac{\sqrt{2}}{3} \left(\frac{X_C}{X_L} \right) \text{ i.e., independent of load resistance}$$

$$X_L = \omega L \text{ or } 2\omega L \text{ for HW and forward}$$

$$X_C = \frac{1}{\omega C} \text{ or } \frac{1}{2\omega C} \text{ for HW and forward}$$

Multiple LC Section filter:

$$r = \frac{\sqrt{2}}{3} \left(\frac{X_C}{X_L} \right)^n$$

CLC (π) Filter

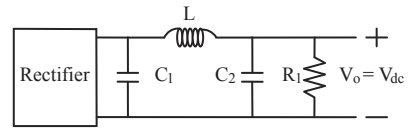


Fig. 7.86

$$r = \sqrt{2} \left(\frac{X_{C_1}}{R_L} \right) \left(\frac{X_{C_2}}{X_L} \right)$$

CRC (π) Filter:

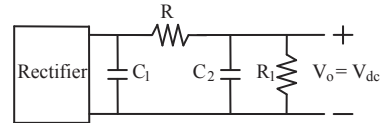


Fig. 7.87

$$r = \sqrt{2} \left(\frac{X_{C_1}}{R_L} \right) \left(\frac{X_{C_2}}{R} \right)$$

Critical Inductance

The value of the inductance used in LC section filter must be kept above a certain minimum value called the **critical inductance**. The value of this inductor is chosen in such a way, so that the dc current flows through it all the time. For this to flow continuously, we must have peak ac current less than or equal to the dc components of the current

$$I_{dc} \geq I_{peak}$$

$$\frac{V_{dc}}{V_L} \geq \sqrt{2} I'_{rms}$$

$$\frac{V_d}{R_L} \geq \sqrt{2} \cdot \frac{\sqrt{2}}{3} \left(\frac{V_{dc}}{X_L} \right)$$

$$X_L \geq \frac{2}{3} R_L$$

Bleeder Resistance Function

1. To maintain the minimum current necessary for optimum inductor operation.
2. Used as a voltage divider in providing output voltage from the supply.
3. It serves as a discharge path for capacitor which may be induced in the circuit so that the voltage does not remain across the output terminal of power supply for an indefinitely long period of time after the load has been disconnected and the current dc-energies.
4. Reduces voltage regulation.

Regular Voltage Regulator Using Zener Diode

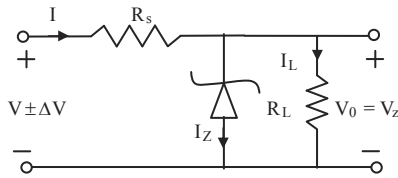


Fig. 7.88

Condition for regulation is $(V + \Delta V) \geq |V_z|$.

Case 1:

When $V_{i \max}$ and $R_{L \max}$ (no load)

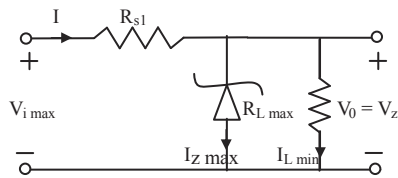


Fig. 7.89

$$R_{\min} = R_{s1} \geq \frac{V_i(\max) - V_z}{I_z(\max) + I_L(\min)}$$

Case 2:

When $V_{i \min}$ and $R_{L \min}$ (maximum load current) this worst case

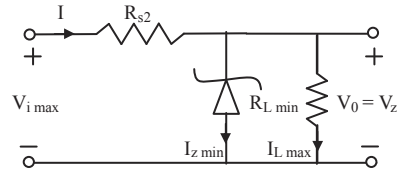


Fig. 7.90

$$R_{\max} = R_{s2} = \frac{V_i(\min) - V_z}{I_z(\min) + I_L(\min)}$$

Practically $I_{z(\min)} = 0.2$ of I_z (rated)

$I_{z(\max)} = 0.8 I_z$ (rated).

- Series regulator is preferable for:
 1. High voltage
 2. High output currents
 3. Relatively varying loads.
- Shunt regulator is preferred for:
 1. Medium to low voltages
 2. High currents
 3. Relatively constant loads.
- Emitter follower voltage regulator are limited to preferred for:
 1. Low output voltage
 It has poor ripple suppression and poor regulation with respect to variation in the input voltage variation.

Regulation Factor

$$S = \left. \frac{\Delta V_o}{\Delta V_i} \right|_{\Delta I_L = 0}$$

At constant temperature, $\Delta T = 0$ regulation should be low for good regulation.

QUESTION BANK

LEVEL 1

1. As compared to a full-wave rectifier using two diodes, the four diode rectifier has the dominant advantage of
 - (a) Higher current carrying
 - (b) Lower peak inverse voltage requirement
 - (c) Lower ripple factor
 - (d) Higher efficiency
2. The bandwidth of an RC-coupled amplifier is limited by
 - (a) Coupling capacitors at the low-frequency end and bypass capacitors at the high-frequency end
 - (b) Coupling capacitors at the high frequency end and bypass capacitors at the low-frequency end
 - (c) Bypass and coupling capacitors at the low frequency end and shunt capacitors at the high frequency end
 - (d) Shunt capacitors at the low frequency end and bypass as well as coupling capacitors at the high frequency end
3. Schottky diodes, also called hot carrier diode, are used in wave shaping circuits because
 - (a) They have a small recovery time
 - (b) They have a large reverse resistance
 - (c) They have a large forward current
 - (d) Their peak inverse voltage is small
4. In an L-section filter, a bleeder resistance connected across the load
 - (a) Provides good regulation for all values of load
 - (b) Ensures lower PIV of the diodes
 - (c) Ensures lower values of capacitance in the filter
 - (d) Reduces ripple content
5. Which one of the following statements regarding filters is correct?
 - (a) Butter-worth response has a sharp cutoff
 - (b) Chebyshev response has a flat response in the pass band
 - (c) Butter-worth response has ripples on the pass band
 - (d) Chebyshev response has ripple in the pass band
6. The current range in a voltage regulator can be improved by
 - (a) Increasing the input voltage
 - (b) Decreasing the reference voltage
 - (c) By putting the control potentiometer at the highest setting
 - (d) Replacing the series transistor by a Darlington pair
7. The larger is the value of filter capacitor
 - (a) Larger is the peak-peak value of ripple voltage
 - (b) Larger is the peak-current in the rectifying diode
 - (c) Longer is the time that correct pulse flows through the diode
 - (d) Smaller is the dc voltage across the load
8. The function of a bleeder resistor in a rectifier with LC filter is to
 - (a) Maintain the minimum current through C
 - (b) Maintain the minimum current necessary for optimum inductor operation
 - (c) Maintain maximum current through L
 - (d) Charge the capacitor C to maximum value.
9. The dissipation at the collector is in the quiescent state and increases with excitation in the case of a
 - (a) Class A series-fed amplifier
 - (b) Class A transistor coupled amplifier
 - (c) Class AB amplifier
 - (d) Class B amplifier
10. In a feedback series regulator circuit, the output voltage is regulated by controlling the
 - (a) Magnitude of the input voltage
 - (b) Gain of the feedback transistor
 - (c) Reference voltage
 - (d) Voltage drop across the series pass transistor
11. The three-terminal monolithic IC regulator can be used as
 - (a) An adjustable output voltage regulator alone
 - (b) An adjustable output voltage regulator and a current regulator
 - (c) A current regulator and a power switch
 - (d) A current regulator alone
12. A Hartley oscillator is used for generation
 - (a) Very low frequency oscillation
 - (b) Radio frequency oscillation
 - (c) Microwave oscillation
 - (d) Audio-frequency oscillation
13. A Schottky diode clamp is used along with a switching BJT for
 - (a) Reducing the power dissipation
 - (b) Reducing the switching time
 - (c) Increasing the value of β
 - (d) Reducing the base current
14. The most preferred high power output stage for hi-fi A.F. amplifier is of the
 - (a) Class B push type
 - (b) Class B single ended type
 - (c) Class A type
 - (d) Class C type
15. Most of the linear ICs are based on the two transistor differential amplifier because of its
 - (a) Input voltage dependent linear transfer characteristic
 - (b) High voltage gain
 - (c) High input resistance
 - (d) High CMRR
16. Schottky barrier diode can be used as
 - (a) Low noise amplifier
 - (b) Variable capacitance device
 - (c) Power supply rectifier
 - (d) Low level detector

17. The bandwidth of an RF tuned amplifier is dependent on
 - (a) Q factor of the tuned output circuit
 - (b) Q factor of the tuned input circuit
 - (c) Quiescent operating point
 - (d) Q factors of the output and input circuits as well as the quiescent operating point
18. Which one of the following oscillators is used for generation of high frequencies?
 - (a) R.C phase shift
 - (b) Wine Bridge
 - (c) L.C. oscillator
 - (d) Blocking oscillator
19. Which one of the following statements is true of phase shift type and wein bridge type RC oscillators?
 - (a) Both use positive feedback
 - (b) The former uses positive feedback only whereas the latter uses both positive and negative feedback
 - (c) The former uses both positive and negative feedback, whereas the latter uses positive feedback only
 - (d) Both use negative feedback
20. In order to achieve maximum bias stability for a transistor with a given power loss, it is necessary to use
 - (a) Non-linear temperature- sensitive elements
 - (b) Linear temperature sensitive elements
 - (c) A series combination of linear and non-linear temperature sensitive elements
 - (d) A parallel combination of linear and non-linear temperature sensitive elements
21. Class AB operation is often used in power (large signal) amplifier in order to
 - (a) Get maximum efficiency
 - (b) Remove even harmonics
 - (c) Overcome cross-over distortion
 - (d) Reduces collector dissipation
22. In a common emitter amplifier, the unbypassed emitter resistance provides
 - (a) Voltage-shunt feedback
 - (b) Current-series feedback
 - (c) Negative-voltage feedback
 - (d) Positive-current feedback
23. If properly biased, JFET will act as a
 - (a) Current controlled current source
 - (b) Voltage controlled voltage source
 - (c) Voltage controlled current source
 - (d) Current controlled voltage source
24. If an intrinsic semiconductor is doped with a vary small amount of boron, then in the extrinsic semiconductor so formed, the number of electrons and holes will
 - (a) Decrease
 - (b) Increase and decrease respectively
 - (c) Increase
 - (d) Decrease and increase respectively
25. The drain source voltage at which the drain current becomes nearly constant is called
 - (a) Barrier voltage
 - (b) breakdown voltage
 - (c) Pick-off voltage
 - (d) Pinch-off voltage
26. In the case of a BJT amplifier, bias stability is achieved by
 - (a) Keeping the base current constant
 - (b) Changing the base current in order to keep I_c and V_{CE} constant
 - (c) Keeping the temperature constant
 - (d) Keeping the temperature and the base current constant
27. A transformer coupled amplifier would give
 - (a) Maximum voltage gain
 - (b) Impedance matching
 - (c) Maximum current gain
 - (d) Larger bandwidth
28. The overall bandwidth of two identical voltage amplifiers connected in cascade will
 - (a) Remain the same as that of a single stage
 - (b) Be worse than that of a single stage
 - (c) Be better than that of single stage
 - (d) Be better if stage gain is low and worse if stage gain is high
29. If the counters of INTEL 8253 (programmable interval timer) are loaded with a new value while counting, then
 - (a) The counter will stop counting
 - (b) Counter will ignore the new loaded value and continue to count as per pervious loaded value
 - (c) The counter will start counting backwards
 - (d) Counting will restart from the new of count which has been loaded
30. If the shunt series feedback amplifier, the basic amplifier and the feedback network are parallel connected at the input and series connected at the output, the signal sampled and the summing down will be respectively
 - (a) Current and current
 - (b) Current and voltage
 - (c) Voltage and current
 - (d) Voltage and voltage
31. In an inverting amplifier, the two input terminals of an ideal Op-amp are at the same potential because
 - (a) The two input terminals are directly shorted internally
 - (b) The input impedance of the Op-amp is infinity
 - (c) CMRR is infinity
 - (d) The open-loop gain of the Op-amp is infinity
32. Consider the following statements: A tunnel diode is
 - (a) Made up of Ge or GaAs
 - (b) An abrupt junction with both sides heavily doped
 - (c) A hyper abrupt junction with both sides heavily doped
 - (d) A majority carrier device
 Which of these statements are correct?
 - (a) 1 and 2
 - (b) 3 and 4
 - (c) 1, 3 and 4
 - (d) 1, 2 and 4

33. Consider the following features regarding an amplifier:

1. Voltage gain being less than one.
2. High input impedance
3. High output impedance
4. High current gain

Which of these are the characteristic features of an emitter follower amplifier?

- (a) 1, 2 and 4
- (b) 1, 2 and 3
- (c) 1 and 3
- (d) 2, 3 and 4

34. In an RC coupled amplifier, the gain decreases in the frequency response due to the

- (a) Coupling capacitor at low frequency and bypass capacitor at high frequency
- (b) Coupling capacitor at low frequency and bypass capacitor at low frequency
- (c) Coupling junction capacitance at low frequency and coupling capacitor at high frequency
- (d) Device junction capacitor at high frequency and coupling capacitor at low frequency

35. Active load is used in the collector of the differential amplifier of op-amp to

- (a) Increase the output resistances
- (b) Increase the differential gain A_d
- (c) Increase maximum peak output voltage
- (d) Eliminate load resistance from the circuit

36. A sinusoidal waveform can be converted to a square waveform by using a

- (a) Two stage transistorized overdriven amplifier
- (b) Two stage diode detector circuit
- (c) Voltage comparator based on op-amp
- (d) Regenerative voltage comparator circuit

37. High power efficiency of the push-pull amplifier is due to the fact that

- (a) Each transistor conducts on different cycle of the input
- (b) Transistor are placed in CE configuration
- (c) There is no quiescent collector current
- (d) Low forward biasing voltage is required

38. Consider the following with reference to a CE transistor amplifier

- (a) The use of negative feedback
- (b) The conversion of dc power ac
- (c) High voltage and current gains
- (d) The use of a step-up transformer

The power gain is due to

- (a) 1 and 2
- (b) 2 and 3
- (c) 1 and 3
- (d) 1 and 4

39. Which one of the following statements is correct?

A photodiode works on the principle of

- (a) Photo-voltaic effect
- (b) Photo-conductive effect
- (c) Photo-electric effect
- (d) Photo-thermal effect

40. Which one of the following statements is correct?

The efficiency of class B push-pull amplifier is much higher than that of class A amplifier primarily because

- (a) The distortion is kept within acceptable limit
- (b) One half of the input signal is amplified using one transistor and the other half is phase inverted and fed to the other transistor
- (c) Matched pair transistors are used in the class B push-pull operation
- (d) The quiescent dc current is avoided

41. Consider following statements:

1. BJT is a current controlled device with high input impedance and high gain bandwidth
2. FET is a voltage controlled device with high input impedance and low gain bandwidth
3. UJT is a negative resistive device and can be used as an oscillator
4. BJT, FET and UJT can all be used for amplification

Which of the statements given above are correct?

- (a) 1 and 2
- (b) 2 and 3
- (c) 3 and 4
- (d) 1 and 4

42. An emitter in a bipolar junction transistor is doped much more heavily than the base as it increases the

- (a) Emitter efficiency
- (b) Base transport factor
- (c) Forward current gain
- (d) All the three given above

43. Which one of the following statements is correct?

In the case of load regulation

- (a) When the temperature changes, the output voltage remains constant
- (b) When the input voltage changes the load current remains constant
- (c) When the load changes, the load current remains constant
- (d) When the load changes, the output voltage remains constant

44. Which one of the following statements is correct?

A Darlington amplifier as

- (a) Large current gain and high input resistance
- (b) Large voltage gain and low output resistance
- (c) Small voltage gain and low input resistance
- (d) Small current gain and high output resistance

45. The gain of a bipolar transistor drops at high frequencies

- (a) Coupling and bypass capacitors
- (b) Early effect
- (c) Inter electrode transistor capacitances
- (d) Coupling and bypass capacitors, and inter electrode transistor capacitances

46. SCR can be turned on by

1. Applying anode voltage at a sufficiently fast rate
2. Applying sufficiently large anode voltage
3. Increasing the temperature of SCR to a sufficiently large value
4. Applying sufficiently large gate current

Of these statements:

- (a) 1, 2, 3 are correct (b) 1, 3 are correct
(c) 1, 2, 4 are correct (d) 2, 3, 4, are correct
47. A P-N junction in series with a 100 ohms resistor is forward biased so that a current of 100 mA flows. If the voltage across this combination is instantaneously reversed to 10 V at $t = 0$, the reverse current that flows through the diode at $t = 0$ is approximately given by
(a) 0 mA (b) 100 mA
(c) 200 mA (d) 50 mA
48. If large amounts of power are required, a push-pull amplifier is designed for operation as
(a) class-A (b) class-B
(c) class-AB (d) class-C
49. Two transistors have the same value of α but different current gain-bandwidth products. One of them is a germanium transistor and the other is a silicon transistor. Both the transistors have similar geometries and the value of the base width. The transistor with lower GB product
(a) Is germanium
(b) Is silicon
(c) May be either of two
(d) Cannot be identified unless more information available.
50. A Darlington pair is used for
(a) Low distortion (b) High frequency range
(c) High power gain (d) High current gain
51. An ideal power supply is
(a) Zero internal resistance
(b) Very larger input resistance
(c) Very small output resistance
(d) Very large output resistance
52. For an n-channel JFET, having drain-source voltage constant if the gate-source voltage is increased (more negative) pinch-off would occur for
(a) High value of drain current
(b) Saturation value of drain current
(c) Zero drain current
(d) Gate current equal to the drain current
53. When a junction transistor is operated under saturated conditions
(a) Both the CB and EB junctions are forward biased
(b) The CB junction is forward biased but the EB junction is reverse biased
(c) The CB junction is reverse biased but the EB junction is forward biased
(d) Both the CB and EB junction are reverse biased
54. The figure of merit of a logic family is given by
(a) Gain x bandwidth
(b) Propagation delay time x power dissipation
(c) Fan-out x propagation delay time
(d) Noise margin x power dissipation
55. A 1 ms pulse can be stretched to 1 pulse by using
(a) An astable multivibrator
(b) A Monostable multivibrator
(c) A bistable multivibrator
(d) A schmitt trigger circuit
56. A FET is a better chopper than a BJT because it has
(a) Lower off-set voltage
(b) Higher series ON resistance
(c) Lower input current
(d) Higher input impedance
57. Consider the following statements regarding the bootstrap biasing arrangement for a BJT emitter follower:
1. The input impedance is very high
2. The voltage gain is exactly equal to one
3. The output impedance is equal to zero
Which of these statements is correct?
(a) None (b) 2 alone
(c) 3 alone (d) 1 alone
58. Consider the following statements:
The lower cutoff frequencies for a RC coupled CE amplifier depend on
1. Input and output coupling capacitors
2. Emitter by pass capacitors
3. Junction capacitors
Which of these statements is/are correct?
(a) 1 alone (b) 2 alone
(c) 1 and 2 (d) 2 and 3
59. Which one of the following power amplifiers has the maximum efficiency?
(a) Class A (b) Class B
(c) Class AB (d) Class C
60. If the Q of a single-stage single-tuned amplifier is doubled, then its bandwidth will
(a) remain same (b) become half
(c) become double (d) become for times
61. Consider the following statements is relation to a large value of capacitor filter used in a full-wave rectifier:
It gives the
1. Low conduction period for the diode rectifier
2. Increased peak current rating of the diode
3. Large peak inverse voltage rating of the diode
Which of these statements are correct?
(a) 1, 2 and 3 (b) 2 and 3
(c) 1 and 2 (d) 1 and 3
62. In every practical oscillator, the loop gain is slightly larger than unity and the amplitude of the oscillation is limited by the
(a) Magnitude of the loop gain
(b) Onset if non-linearity
(c) Magnitude of gain of the amplifier
(d) Feedback transmission factor

63. The essential blocks of a phase lock loop (PLL) are detector, amplifier,
 (a) High-pass filter and crystal controlled oscillator
 (b) Low-pass filter and crystal controlled oscillator
 (c) High-pass filter and voltage controlled oscillator
 (d) Low-pass filter and voltage controlled oscillator
64. Thermal runaway is not possible in FET because as the temperature of FET increases
 (a) The mobility decreases
 (b) The trans conductance increases
 (c) The drain current increases
 (d) The mobility increases
65. Consider the following rectifier circuits:
 1. Half-wave rectifier without filter
 2. Full-wave rectifier without filter
 3. Full-wave rectifier with series inductance filter
 4. Full-wave rectifier with capacitance filter
 The sequence of these rectifier circuit in decreasing order of their ripple factor is
 (a) 1, 2, 3, 4
 (b) 3, 4, 1, 2
 (c) 1, 4, 3, 2
 (d) 3, 2, 1, 4
66. The use of a capacitor filter in a rectifier circuit gives satisfactory performance only when the load
 (a) current is high (b) current is low
 (c) voltage is high (d) voltage is low
67. The main drawback in the performance of shunt peaked wide band amplifier is
 (a) Too low gain at low frequency
 (b) Reduced gain at middle frequency
 (c) Poor phase response
 (d) That the maximum gain of the stage is small
68. The IF amplifier in a super heterodyne receiver is
 (a) Single-stage single-tuned amplifier
 (b) Two stages of single-tuned amplifier
 (c) Double tuned amplifier
 (d) Class-C amplifier
69. Which one of the following circuits is most suitable as an oscillator at a frequency of 100 Hz
 (a) Hartley oscillator
 (b) Colpitts oscillator
 (c) Crystal oscillator
 (d) Twin-T oscillator
70. A differential amplifier is invariably used in input stage of all op-amps. This is done basically to provide the op-amps with a very high
 (a) CMRR
 (b) bandwidth
 (c) slow rate
 (d) open-loop gain
71. The effect of a finite gain of an operational amplifier used in an integrator is that
 (a) It would not integrate
 (b) The slope of the output will vary with time
 (c) The final value of the output voltage will reduce
 (d) There will be instability in the circuit
72. In a PLL, lock occurs when the
 (a) Input frequency and the VCO frequency are the same
 (b) Phase error is 180°
 (c) VCO frequency is double the input frequency
 (d) Phase error is 90°
73. An operational amplifier possesses
 (a) Very large input resistance and very large output resistance
 (b) Very large input resistance and very small output resistance
 (c) Very small input resistance and very small output resistance
 (d) Very small input resistance and very large output resistance
74. Consider the following statements:
 In order to generate square wave from a sinusoidal input signal one can use
 1. Schmitt trigger circuit
 2. Clippers and amplifiers
 3. Monostable multivibrator
 Which of the above statements is/are correct?
 (a) 1 alone (b) 1 and 2
 (c) 2 and 3 (d) 1, 2 and 3
75. In a BJT amplifier, with the introduction of feedback, the input impedances is reduced, output impedance is increased, bandwidth is increased and distortion is reduced. The feedback is
 (a) Voltage series (b) Current series
 (c) Voltage shunt (d) Current shunt
76. Which one of the following statement is not correct in respect of a series transistor feedback voltage regulator?
 (a) The regulation factor can be improved by increasing the h_{fe} of the shunt transistor
 (b) The regulation factor can be improved by increasing the resistance between the collector of the shunt transistor and the collector of the series transistor.
 (c) Output resistance can be reduced by using a Darlington pair in place of the series transistor
 (d) Output resistance can be reduced by reducing the h_{fe} of the shunt transistor
77. What is the main advantage of a JFET-cascade amplifier?
 (a) High voltage gain
 (b) Low output impedance
 (c) Very low input capacitance
 (d) High input impedance
78. SCR turns OFF conducting state to blocking state on
 (a) Reducing gate current
 (b) Reversing gate voltage
 (c) Reducing anode current below holding current value
 (d) Applying ac to the gate

79. The Hysteretic phenomenon in Schmitt Trigger has, which of the following features:

1. It is due to negative feedback
2. In the inverted mode, circuit triggers at a higher voltage for increasing signals than for decreasing signals
3. Noise signal voltages greater than V_H are cutoff where V_H is the Hysteretic voltage.
4. Slowly varying signals are converted to output waveform with abrupt changes at two specified levels of input signals

Of these four statements, the true statements are:

- (a) 2 and 3 only
- (b) 2 and 4 only
- (c) 2, 3 and 4 only
- (d) 3 and 4 only

80. The 'h' parametre equivalent circuit of a junction transistor is valid for

- (a) High frequency, large signal operation
- (b) High frequency, small signal operation
- (c) Low frequency, small signal operation
- (d) Low frequency, large signal operation

81. SCR can be turned on by

1. Applying anode voltage at a sufficiently fast rate
2. Applying sufficiently large anode voltage
3. Increasing the temperature of SCR to a sufficiently large value
4. Applying sufficiently large gate current

Of these statements:

- (a) 1, 2, 3 are correct
- (b) 1, 3 are correct
- (c) 1, 2, 4 are correct
- (d) 2, 3, 4, are correct

82. The phenomenon known as "Early Effect" in a bipolar transistor refers to a reduction of the effective base – width caused by

- (a) Electron – hole recombination at the base
- (b) The reverse biasing of the base – collector junction
- (c) The forward biasing of emitter-base junction
- (d) The early removal of stored base charge during saturation to cutoff switching

LEVEL 2

1. If an N-P-N silicon transistor is operated at $V_{CE} = 5V$ and $I_c = 100$ microamperes and has a current gain of 100 in the CE connection, then input resistance of this circuit will be

- (a) 250Ω
- (b) 2500Ω
- (c) 25Ω
- (d) 250Ω

2. The maximum theoretical efficiency of a Class B push-pull transistor amplifier is approximately

- (a) 25%
- (b) 50%
- (c) 70.7%
- (d) 78.6%

3. A source follower using an FET usually has a voltage gain which is

- (a) Greater than +100
- (b) Slightly less than unity but positive
- (c) Exactly unity but negative
- (d) About -10

4. High threshold MOSFET can be obtained by using silicon orientation

- (a) $\langle 100 \rangle$
- (b) $\langle 101 \rangle$
- (c) $\langle 110 \rangle$
- (d) $\langle 111 \rangle$

5. The output time period of a transistorized monostable multivibrator using base resistor R_b and coupling capacitor C_b for the output transistor is given by

- (a) $R_b C_b$
- (b) $0.69 R_b C_b$
- (c) $2 R_b C_b$
- (d) $1.38 R_b C_b$

6. If $\alpha = 0.98$, $I_{co} = 6 \mu A$ and $I_B = 100 \mu A$ for a transistor, then value of I_c will be

- (a) 2.3 mA
- (b) 3.1 mA
- (c) 4.6 mA
- (d) 5.2 mA

7. An amplifier with mid-band gain $|A| = 500$ has negative

feedback $|\beta| = \frac{1}{100}$. If the upper cutoff frequency without

feedback were at 60 kHz, then with feedback it would become

- (a) 10 kHz
- (b) 12 kHz
- (c) 300 kHz
- (d) 360 kHz

8. If the differential and common mode gains of a differential amplifier are 50 and 0.2 respectively, then the CMRR will be

- (a) 10
- (b) 49.8
- (c) 50.2
- (d) 250

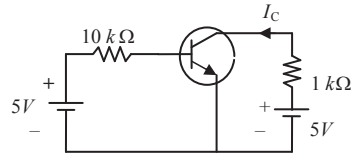
9. An FET source follower circuit has g_m of 2 m mho and r_d of $50 k\Omega$. If the source resistance R_s is $1 k\Omega$, the output resistance of the amplifier will be

- (a) 330Ω
- (b) 450Ω
- (c) 500Ω
- (d) $1 k\Omega$

10. A transistor amplifier has a voltage gain of 50, input resistance of $1 k\Omega$ and output resistance of $40 k\Omega$. The amplifier is now provided 10% negative voltage feedback in series with the input. With feedback, the voltage gain, input resistance and output resistance will be respectively

- (a) 87 k Ω and 3 k Ω
- (b) 8.33, 6 k Ω and 6.66 k Ω
- (c) 5.33, 8.33 k Ω and 8.66 k Ω
- (d) 6.66, 8.86 k Ω and 6.66 k Ω

11. A two-stage amplifier is required to have an upper cutoff frequency of 2 MHz and a lower cutoff frequency of 30 Hz. The upper and lower cutoff frequencies of individual stage are respectively approximately
 (a) 4 MHz, 60 Hz (b) 3 MHz, 20 Hz
 (c) 3 MHz, 60 Hz (d) 4 kHz, 20 Hz
12. If V_m is peak value of an applied in a half wave rectifier with a large capacitor across the load, then the peak inverse voltage will be
 (a) $\frac{V_m}{2}$ (b) V_m
 (c) $\sqrt{2} V_m$ (d) $2 V_m$
13. A saw-tooth generator is built using a UJT with a constant-current-charged capacitor C of $1 \mu\text{f}$ driving the emitter. If the voltage V_{BB} is 15 V and the capacitor charging current is 1 mA, then the period of the saw-tooth is approximately
 (a) 10 ms (b) 1 ms
 (c) 0.1 ms (d) 0.01 ms
14. The minimum value of h_{fe} of a transistor to be used in three sections R - C phase shift oscillator is
 (a) 54.4 (b) 45.4
 (c) 44.5 (d) 29
15. The upper 3 dB frequency in a common emitter amplifier is given in terms of the hybrid parameters as
 (a) $\frac{g_m}{2\pi C}$ (b) $\frac{g_b'e}{C}$
 (c) $\frac{h_{fe}}{g_b'e}$ (d) $\frac{g_m}{h_{fe}}$
16. A class-B push pull power amplifier uses two transistors each having a power dissipation capacity of 2 watts. The maximum power that the circuit delivers to the load without extending the power dissipation capacity of the transistors is to the load without extending the power dissipation capacity of the transistors is
 (a) 1 watt (b) 2 watts
 (c) 5 watts (d) 10 watts
17. The output voltage of the circuit shown in the given figure is
 (a) -10.2 V (b) -8.8
 (c) zero (d) 0.2
18. If $\alpha = 0.995$, $I_E = 10 \text{ mA}$ and $I_{CBO} = 0.5 \text{ mA}$, then I_{CEO} will be
 (a) $100 \mu\text{A}$ (b) $25 \mu\text{A}$
 (c) $10.1 \mu\text{A}$ (d) $10.5 \mu\text{A}$
19. The approximate value of input impedance of a common emitter amplifier with emitter resistance R_e is given by
 (a) $h_{ie} + A_f R_e$ (b) $h_{ie} + (1 + h_{fe}) R_e$
 (c) h_{ie} (d) $(1 + h_{fe}) R_e$
20. If an amplifier with gain of $A = 1000$ and feedback of $B = -0.1$ had a gain change of 20% due to temperature, the change in gain of the feedback amplifier would be
 (a) 10% (b) 5%
 (c) 0.2% (d) 0.01%
21. If the input ac is 10 V rms, the maximum voltage that will appear across the diode of a half-wave rectifier with a capacitor input filter will be
 (a) 10 V (b) 14 V
 (c) 20 V (d) 28 V
22. Thermal runaway will take place if the quiescent point is such that
 (a) $V_{CE} > \left(\frac{1}{2}\right) V_{CC}$ (b) $V_{CE} < V_{CC}$
 (c) $V_{CE} < 2 V_{CC}$ (d) $V_{CE} < \left(\frac{1}{2}\right) V_{CC}$
23. If a class C power amplifier has an input signal frequency of 200 kHz and the width of collector current pulses of $0.1 \mu\text{s}$, then the duty cycle of the amplifier will be
 (a) 1% (b) 2%
 (c) 10% (d) 20%
24. A transistor has CE parametre as $h_{ie} = 10 \text{ k}\Omega$, $h_{re} = 20 \times 10^{-4}$, $h_{fe} = 100$, $h_{oe} = 25 \mu\text{s}$. The h_{ib} for this transistor will be
 (a) 100Ω (b) 99.01Ω
 (c) $5 \text{ M}\Omega$ (d) $101 \text{ K}\Omega$
25. In the PNP transistor circuit shown in the given figure, the transistor is in saturation with values of $V_{be} = 0.7 \text{ V}$, $V_{ce(\text{sat})} = 0.3 \text{ V}$ and $\beta_{\min} = 20$. The value of I_C will be



- (a) 7 mA (b) 5.3 mA
 (c) 8.6 mA (d) 10 mA
26. If V_m is peak value of an applied voltage in a half-wave rectifier with a large capacitor across the load, then the peak inverse voltage will be
 (a) $V_m/2$ (b) V_m
 (c) $\sqrt{2} V_m$ (d) $2 V_m$
27. The upper cutoff frequencies f_{21} and f_{22} of the two stages of a cascaded amplifier are respectively 5 MHz and 3.3 MHz. The equivalent upper cutoff frequency of the cascaded amplifier would be
 (a) 4.16 MHz (b) 3.33 MHz
 (c) 2.51 MHz (d) 5 MHz
28. An amplifier circuit has an overall current gain of 100 and an input resistance of $10 \text{ k}\Omega$ with a load resistance of $1 \text{ k}\Omega$. The overall voltage gain of the amplifier is
 (a) 5 dB (b) 10 dB
 (c) 20 dB (d) 40 dB
29. An op amp-has a common mode gain of 0.01 and a differential mode gain of 10^5 . Its common mode rejection ratio would be
 (a) 10^{-7} (b) 10^{-3}
 (c) 10^3 (d) 10^7

30. The Barkhausen criterion for sustained oscillation is given by

(a) $|A\beta| = 1$ (b) $|A\beta| \geq 1$
 (c) $|A\beta| < 1$ (d) $\angle A\beta = 180^\circ$

31. A specimen of intrinsic germanium with the density of charge carriers of $2.5 \times 10^{13}/\text{cm}^3$, is doped with donor impurity atoms such that there is one donor impurity atom for every 10^6 germanium atoms. The density of germanium atoms is $4.4 \times 10^{22}/\text{cm}^3$. The hole would be

(a) $4.4 \times 10^{16}/\text{cm}^3$ (b) $1.4 \times 10^{10}/\text{cm}^3$
 (c) $4.4 \times 10^{10}/\text{cm}^3$ (d) $1.4 \times 10^{16}/\text{cm}^3$

32. If for intrinsic Silicon at 27°C , the charge concentration and mobilities of free-electrons and holes are 1.5×10^{16} Per m^3 , $0.13 \text{ m}^2/(Vs)$, $0.05 \text{ m}^2/(Vs)$

Respectively, its conductivity will be

(a) $2.4 \times 10^3 (\Omega - \text{m})^{-1}$ (b) $3.15 \times 10^3 (\Omega - \text{m})^{-1}$
 (c) $5 \times 10^{-4} (\Omega - \text{m})^{-1}$ (d) $4.32 \times 10^3 (\Omega - \text{m})^{-1}$

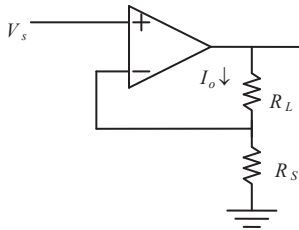
33. An amplifier having an output resistance of 4Ω gives an open circuit output voltage of 6 V(rms) . The maximum power that it can deliver to a load is

(a) 1.5 W (b) 2.25 W
 (c) 2.4 W (d) 9 W

34. The slew rate of an op amp is $0.5 \text{ V/micro secone}$. The maximum frequency of a sinusoidal input of 2 V rms that can be handled without excessive distortion is

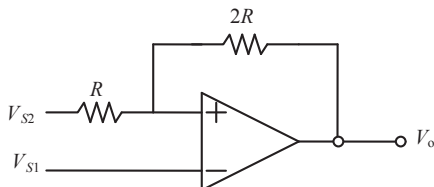
(a) 3 kHz (b) 30 kHz
 (c) 200 kHz (d) 2 kHz

35. An op amp is used in the circuit as shown in the below figure. Current I_o is



(a) $V_s \times \frac{R_L}{R_s(R_L + R_s)}$ (b) $\frac{V_s}{R_s}$
 (c) $\frac{V_s}{R_L}$ (d) $V_s \left(\frac{1}{R_s} + \frac{1}{R_L} \right)$

36. A circuit with op amp is shown in the below figure. The voltage V_o is



(a) $3V_{s1} - 6V_{s2}$ (b) $2V_{s1} - 3V_{s2}$
 (c) $2V_{s1} - 2V_{s2}$ (d) $3V_{s1} - 2V_{s2}$

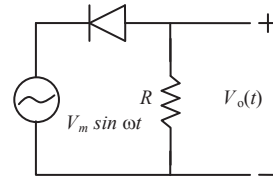
37. The junction capacitance of a linearly graded junction varies with the applied reverse bias V_r as

(a) V_r^{-1} (b) $V_r^{-1/2}$
 (c) $V_r^{-1/3}$ (d) $V_r^{1/2}$

38. The modified work function of an n-channel MOSFET is -0.85 V . If the interface charge is $3 \times 10^{-4} \text{ C/m}^2$ and the oxide capacitance is $300 \mu\text{F m}^2$, the flat band voltage is

(a) -1.85 V (b) -0.15 V
 (c) $+0.15 \text{ V}$ (d) $+1.85 \text{ V}$

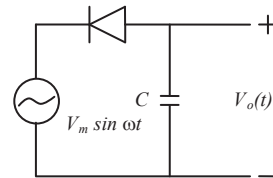
39. In the circuit shown below



The average value of $v_o(t)$ will be

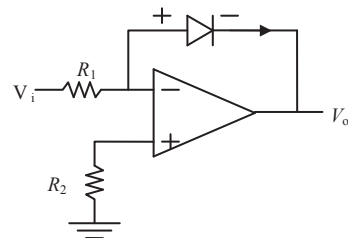
(a) 0 (b) $-V_m / \pi$
 (c) $-V_m / \sqrt{2}$ (d) $-V_m$

40. In the circuit shown below, the average value of $v_o(t)$ will be



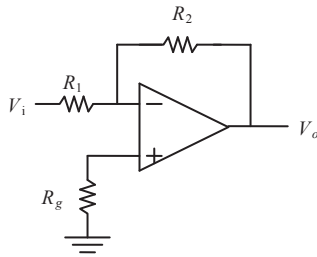
(a) 0 (b) $-V_m / \pi$
 (c) $-V_m / \sqrt{2}$ (d) $-V_m$

41. In the op-amp circuit shown below $v_i > 0$ and $i = I_o \cdot a^{av}$. The output v_o will be proportional to



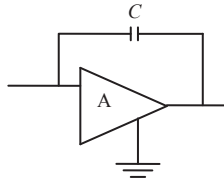
(a) $\sqrt{v_i}$ (b) v_i
 (c) e^{kv_i} (d) $\ln(kv_i)$

42. In the inverting op-amp circuit shown below,



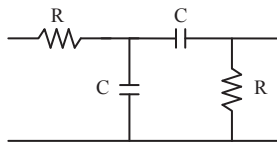
the resistance R_g is chosen as $R_1 \parallel R_2$ is order to

- (a) Increase gain (b) Reduce offset voltage
(c) Reduce offset current (d) Increase CMRR
43. An amplifier of gain A is bridged by a capacitance C as shown below

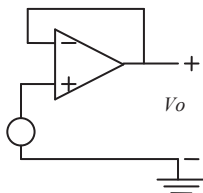


The effective input capacitance is

- (a) $\frac{C}{A}$ (b) $C(1-A)$
(c) $C(1+A)$ (d) CA
44. An Op-amp has a differential gain of 10^3 and a CMRR of 100. The output voltage of the Op-amp with inputs of $120 \mu\text{V}$ and $80 \mu\text{V}$ will be
- (a) 26 mV (b) 41 mV
(c) 100 mV (d) 200 mV
45. An FET oscillator uses the given phase shift network as shown below. The minimum gain required for oscillator is



- (a) -29 (b) 1
(c) 3 (d) 29
46. Consider the following statements with reference to an ideal voltage follower circuit as shown below



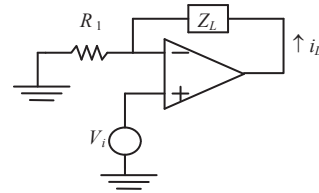
1. Unity gain and no phase shift
2. Infinite gain and 180° phase shift

3. Very high input impedance and very low output impedance
4. It is a buffer amplifier

Which of these statements are correct?

- (a) 1 and 3 (b) 2 and 4
(c) 1, 3 and 4 (d) 1, 2, 3, and 4

47. In the Op-amp circuit as shown below, the current i_L is



- (a) $\frac{V_i}{Z_L}$ (b) $\frac{V_i}{Z_L \parallel R_1}$
(c) $\frac{V_i}{R_1}$ (d) $V_i(R_1 + Z_L)$

48. Two identical RC coupled amplifiers, each having an upper cutoff frequency f_u , are cascaded with negligible loading. What is the upper cutoff frequency of the overall amplifier?

- (a) $\frac{f_u}{\sqrt{\sqrt{2}-1}}$ (b) $f_u \sqrt{\sqrt{2}-1}$
(c) $\frac{f_u}{2}$ (d) $2 f_u$

49. Two identical RC coupled amplifier, each having a lower cutoff frequency f_l , are cascaded with negligible loading. What is the lower cutoff frequency of the overall amplifier?

- (a) $\frac{f_l}{\sqrt{\sqrt{2}-1}}$ (b) $f_l \sqrt{\sqrt{2}-1}$
(c) $\frac{f_l}{2}$ (d) $2 f_l$

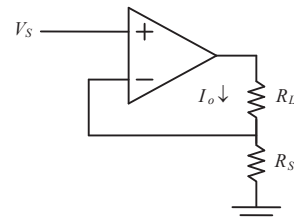
50. Which one of the following statements is correct?

An ideal regulated power supply should have

- (a) 100% regulation (b) 50% regulation
(c) 0% regulation (d) 75 regulation

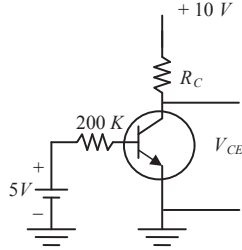
51. Consider the following circuit:

Which one of the following is the correct expression for the current I_o ?



- (a) $\frac{V_s \cdot R_L}{R_S(R_L + R_S)}$ (b) $\frac{V_s}{R_S}$
(c) $\frac{V_s}{R_L}$ (d) $V_s \left(\frac{1}{R_L} + \frac{1}{R_S} \right)$

52. A silicon transistor with $V_{BE_{sat}} = 0.8\text{ V}$, $\beta_{dc} = 100$ and $V_{CE_{sat}} = 0.2\text{ V}$ is used in the circuit shown below. What is the minimum value of R_C for which transistor is in saturations?



- (a) 4286 Ω (b) 4667 Ω
(c) 5000 Ω (d) 1000 Ω
53. In A p-type silicon sample, the hole concentration is $2.25 \times 10^{15}/\text{cc}$. If the intrinsic carrier concentration is $1.5 \times 10^{10}/\text{cc}$, what is the electron concentration in the p-type silicon sample?
- (a) zero (b) $10^{10}/\text{cc}$
(c) $10^5/\text{cc}$ (d) $1.5 \times 10^{25}/\text{cc}$
54. Which one of the following statements is correct?
In a transistor,
- (a) I_{CBO} is greater than I_{CEO} and does not depend upon temperature
(b) I_{CBO} is greater than I_{CO} and double for every ten degrees rise in temperature
(c) I_{CBO} is equal to I_{CO} and doubles for every ten degrees rise in temperature
(d) I_{CEO} is equal to I_{CO} and doubles for every ten degrees rise in temperature
55. The dynamic transfer characteristic for a transistor is required is represented by
 $i_c = A_1 i_b + A_2 i_b^2$
Where, A_1 and A_2 are constants
If input signal $i_b = I_1 \cos \omega_1 t + I_2 \cos \omega_2 t$ the output will contain
- (a) $\omega_1, \omega_2, 2\omega_1, 2\omega_2$
(b) DC term, $\omega_1, \omega_2, \omega_1 + \omega_2, \omega_1 - \omega_2$
(c) DC term $\omega_1, \omega_2, 2\omega_1, + 2\omega_2$
 $2\omega_1 + 2\omega_2, 2\omega_1 - 2\omega_2$
(d) DC term $\omega_1, \omega_2, 2\omega_1, 2\omega_2, \omega_1 + \omega_2, \omega_1 - \omega_2$
56. Find the break region (voltage range) over which the dynamic resistance of a diode is multiplied by a factor of 1000. Let this region be contained between v_1 and v_2 then is $\|v_1 - v_2\|$ given by
- (a) $\log_e (1000V_T)$
(b) $1000 V_T$
(c) $(\log_e 10^3) V_T$
(d) The value cannot be computed with the given data
57. In a centre tap full wave rectifier, 100 V is the peak voltage between the centre tap and one end of the secondary.

What is the maximum voltage across the reverse biased diode?

- (a) 200 V (b) 141 V
(c) 100 V (d) 86 V
58. In a single RC-coupled amplifier stage, what are the phase shifts introduced at lower and upper 3-dB frequencies, respectively?
- (a) $45^\circ, 225^\circ$ (b) $45^\circ, 135^\circ$
(c) $90^\circ, 180^\circ$ (d) $45^\circ, 180^\circ$
59. In a uniformly doped abrupt p-n junction, the doping level of the n-side is four (4) times the doping level of the p-side: The ratio of the depletion layer width is
- (a) 0.25 (b) 0.5
(c) 1.0 (d) 2.0
60. A silicon sample is uniformly doped with 10^{16} phosphorus Atom/ cm^3 and 2×10^{16} boron atoms/ cm^3 . If all the dopants are full ionized, the material is
- (a) n-type with carrier concentration of $10^{16}/\text{cm}^3$
(b) p-type with carrier concentration of $10^{16}/\text{cm}^3$
(c) p-type with carrier concentration of $2 \times 10^{16}/\text{cm}^3$
(d) n-type with carrier concentration of $2 \times 10^{16}/\text{cm}^3$
61. A semiconductor is irradiated with light such that carriers are uniformly generated throughout its volume. The semiconductor is n-type with $N_D = 10^{19}$ per cm^3 . If the excess electron concentration in the steady state is $\Delta n = 10^{15}$ per cm^3 and if $\tau_p = 10 \mu \text{ sec}$ [minority carrier life time] the generation rate due to irradiation
- (a) 10^{20} - e-h pair/ cm^3/s
(b) 10^{24} e-h pairs/ cm^3/s
(c) 10^{10} e-h pairs/ cm^3/s
(d) cannot be determined as the given data is insufficient
62. A P-N junction in series with a 100 ohms resistor, is forward biased so that a current of 100 mA flows. If the voltage across this combination is instantaneously reversed to 10 V at $t = 0$, the reverse current that flows through the diode at $t = 0$ is approximately given by
- (a) 0 mA (b) 100 mA
(c) 200 mA (d) 50 mA
63. A material is described by the following electrical parametres as a frequency of 10 GHz, $\sigma = 10^6$ mho/m, $\mu = \mu_0$ and $\sigma/\sigma_0 = 10$. The material at this frequency considered to be
 $\sigma_0 = \frac{1}{36\pi} 10^{-9} \text{ F/m}$
- (a) A good conductor
(b) A good dielectric
(c) Neither a good conductor, nor a good dielectric
(d) A good magnetic material
64. A small concentration of minority is injected into a homogeneous semiconductor crystal at one point. An electric field of 10V/cm is applied across the crystal and this moves the minority carriers a distance of 1 cm is 20 $\mu \text{ sec}$. The mobility (in $\text{cm}^2/\text{volt}.\text{sec}$)
- (a) 1,000 (b) 2,000
(c) 5000 (d) 5000

65. The probability that an electron in a metal occupies the Fermi-level, at any temperature (> 0 K)
 (a) 0 (b) 1
 (c) 0.5 (d) 0.1
66. The break down voltage of a transistor with its base open is BV_{CEO} and that with emitter open is BV_{CBO} then
 (a) $BV_{CEO} = BV_{CBO}$
 (b) $BV_{CEO} > BV_{CBO}$
 (c) $BV_{CEO} < BV_{CBO}$
 (d) BV_{CEO} is not related to BV_{CBO}
67. In a P type silicon sample, the hole concentration is $2.25 \times 10^{15}/\text{cm}^3$. If the intrinsic carrier concentration is $1.5 \times 10^{10}/\text{cm}^2$, the electron concentration is
 (a) zero (b) $10^{10}/\text{cm}^3$
 (c) $10^5/\text{cm}^3$ (d) $1.5 \times 10^{25}/\text{cm}^3$
68. The depletion capacitance, C_j of an abrupt P-N junction with constant doping on either side varies with reverse bias, V_R , as
 (a) $C_j \propto V_R$ (b) $C_j \propto V_R^{-1}$
 (c) $C_j \propto V_R^{-1/2}$ (d) $C_j \propto V_R^{-1/3}$
69. A n-channel silicon ($E_g = 1.1$ eV) MOSFET was fabricated using n^+ poly-silicon gate and the threshold voltage was found to be 1 V. Now, if the gate is changed to P^+ poly-silicon other things remaining the same the new threshold voltage should be
 (a) -0.1 V (b) 0 V
 (c) 1.0 V (d) 2.1 V
70. The intrinsic carrier density at 300 K is $1.5 \times 10^{10}/\text{cm}^3$, in silicon. For n-type silicon doped to 2.25×10^{15} atoms/ cm^3 , the equilibrium electron and hole densities are
 (a) $n = 1.5 \times 10^{15}/\text{cm}^3$, $p = 1.5 \times 10^{10}/\text{cm}^3$
 (b) $n = 1.5 \times 10^{10}/\text{cm}^3$, $p = 2.25 \times 10^{15}/\text{cm}^3$
 (c) $n = 2.25 \times 10^{15}/\text{cm}^3$, $p = 1.0 \times 10^5/\text{cm}^3$
 (d) $n = 1.5 \times 10^{10}/\text{cm}^3$, $p = 1.5 \times 10^{10}/\text{cm}^3$
71. The electron and hole concentrations in a intrinsic semiconductor are n_i and p_i respectively. When doped with a p-type material, these change to n and p , respectively. Then
 (a) $n + p = n_i + p_i$ (b) $n + ni = p + p_i$
 (c) $np_i = np$ (d) $np = np_i$
72. The f_T of a BJT is related to its g_m , C_π and C_μ as follows
 (a) $f_T = (C_\pi + C_\mu)/g_m$ (b) $f_T = e\pi(C_\pi + C_\mu)/g_m$
 (c) $f_T = g_m/(C_\pi + C_\mu)$ (d) $f_T = g_m/[2\pi(C_\pi + C_\mu)]$
73. The static characteristic of an adequately forward biases p-n junction is a straight line, if the plot is of
 (a) $\log I$ vs. $\log V$ (b) $\log I$ vs. V
 (c) I vs. $\log V$ (d) I vs. V
74. A distorted sinusoid has the amplitudes A_1 , A_2 , A_3 , of the fundamental second third harmonic respectively. The total harmonic distortion is
 (a) $\frac{A_2 + A_3 \dots}{A_1}$ (b) $\frac{\sqrt{A_2^2 + A_3^2 \dots}}{A_1}$
 (c) $\frac{\sqrt{A_2^2 + A_3^2 + \dots}}{\sqrt{A_1^2 + A_2^2 + A_3^2 + \dots}}$ (d) $\frac{1 - \sqrt{A_2^2 + A_3^2 \dots}}{A_1}$
75. The band-gap of silicon at 300 K is
 (a) 1.36 eV (b) 1.10 eV
 (c) 0.80 eV (d) 0.67 eV
76. Intrinsic carrier concentration of silicon sample at 300° K is $1.5 \times 10^{16}/\text{m}^3$. If the after doping, the number of majority carriers is $5 \times 10^{20}/\text{m}^3$, the minority carrier density is
 (a) $4.50 \times 10^{11}/\text{m}^3$ (b) $3.33 \times 10^4/\text{m}^3$
 (c) $5.00 \times 10^{20}/\text{m}^3$ (d) $3.00 \times 10^{-5}/\text{m}^3$
77. An n-type silicon bar 0.1 cm long and $100 \mu\text{m}^2$ in cross sectional area has a majority carrier concentration of $5 \times 10^{20}/\text{m}^3$ and the carrier mobility is $0.13 \text{ m}^2/\text{Vs}$ at 300 K. If the charge of an electron is 1.6×10^{-19} coulomb, then the resistance of the bar is
 (a) 10^6 ohm (b) 10^4 ohm
 (c) 10^{-1} ohm (d) 10^{-4} ohm
78. If P is Passivation, Q is n-well implant, R is metallization and S is source/drain diffusion then the order in which they are carried out in a standard n-well CMOS fabrication process, is
 (a) P-Q-R-S (b) Q-S-R-P
 (c) R-P-S-Q (d) S-R
79. In an abrupt p-n junction, the doping concentrations on the p-side and side are $N_A = 9 \times 10^{16}/\text{cm}^3$ and $N_D = 1 \times 10^{16}/\text{cm}^3$ respectively. The p-n junction is reverse biased and the total depletion width is 3 μm . The depletion width on the p-side is
 (a) 2.7 μm (b) 0.3 μm
 (c) 2.25 μm (d) 0.75 μm
80. The resistivity of a uniform doped n-type silicon sample is $0.5 \Omega\text{-cm}$. If the electron mobility (μ_n) is $1250 \text{ cm}^2/\text{V}$ second and the charge of an electron is 1.6×10^{-19} Coulomb, the donor impurity concentration (N_D) in the sample is
 (a) $2 \times 10^{16}/\text{cm}^3$ (b) $1 \times 10^{16}/\text{cm}^3$
 (c) $2.5 \times 10^{15}/\text{cm}^3$ (d) $5 \times 10^{15}/\text{cm}^3$
81. Consider an abrupt p-junction. Let V_{bi} be the built-in potential of this junction and V_R be the applied reverse bias. If the junction capacitance (C_j) is 1 pF for $V_{bi} + V_R = 1$ V, then for $V_{bi} + V_R = 4$ V, C_j will be
 (a) 4 pF (b) 2 pF
 (c) 0.25 pF (d) 0.5 pF
82. Consider the following statement S1 and S2:
 S1: The threshold voltage (V_T) of a MOS capacitor decreases with increase in gate oxide thickness
 S1: The threshold voltage (V_T) of a MOS capacitor decreases with increase in substrate doping concentration
 Which one of the following is correct?
 (a) S1 is FALSE and S2 is TRUE
 (b) Both S1 and S2 are TRUE
 (c) Both S1 and S2 are FALSE
 (d) S1 is TRUE and S2 is FALSE
83. The longest wavelength that can be absorbed by silicon, which has the band-gap of 1.12 eV, is 1.1 μm . If the longest

wavelength that can be absorbed by another material is 0.87 μm , then the band-gap of this material is

- (a) 1.416 eV (b) 0.886 eV
(c) 0.854 eV (d) 0.706 eV

84. The neutral base width of a bipolar transistor, biased in the active region, is 0.5 μm . The maximum electron concentration and the diffusion constant in the base are $10^{14}/\text{cm}^3$ and $D_n = 25 \text{ cm}^2/\text{sec}$ respectively. Assuming negligible recombination in the base, the collector current density is (the electron charge is 1.6×10^{-19} coulomb)
- (a) 800 A/cm² (b) 8 A/cm²
(c) 200 A/cm² (d) 2 A/cm²

85. When used for amplification, the output port side of a BJT behaves as controlled current source. According to the above, the variation of which one of the following does not change the output current of an ideal BJT? (The BJT is being used in a common emitter amplifier circuit)
- (a) Load resistance
(b) Collector to base bias voltage
(c) Both load resistance and collector to base bias voltage
(d) Base-emitter bias voltage

86. Where does the operating point of a class-B power amplifier lie?
- (a) At the middle of a.c. load line
(b) Approximately at collector cutoff on both the d. c. and a.c. load lines
(c) Inside the collector cutoff region on a.c. load line
(d) At the middle point of dc load line

87. Consider the following statement in respect of a CC amplifier

1. It performs a resistance transformation from low to high resistance
2. Its current gain is close to unity
3. Its voltage gain is close to unity
4. Its frequency range is higher than that of a CE-stage

Which of the statements given above are correct?

- (a) 1, 2 and 4 (b) 1 and 3
(c) Only 2 and 4 (d) 3 and 4

88. An operational amplifier has a slew rate of 100 V/microsecond. For a frequency of 10 MHz, the maximum (peak) value of the sine-wave output voltage will be

- (a) 100 V (b) $50/\pi$ V
(c) 10 V (d) 5 V

89. An amplifier has an input power of 2 microwatts. The power gain of the amplifier is 60 dB. The output power will be

- (a) 6 microwatts (b) 120 microwatt
(c) 2 mill watts (d) 2 watts

90. A BJT has CE parametres as given below

$$h_{ie} = 5 \text{ k ohms}, \quad h_{re} = 10^{-5}$$

$$h_{fe} = 100, \quad h_{oe} = 1.5 \times 10^{-5} \text{ mho}$$

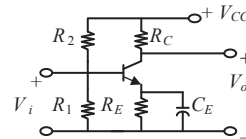
the value of h_{ib} for CB configuration is

- (a) 10^{-5} ohm (b) 49.5 ohms
(c) 5000 ohms (d) 10^5 ohms

91. A differential amplifier has a differential gain of 20,000. CMRR = 80 dB. The common mode gain is given by
- (a) 2 (b) 1
(c) $\frac{1}{2}$ (d) 0

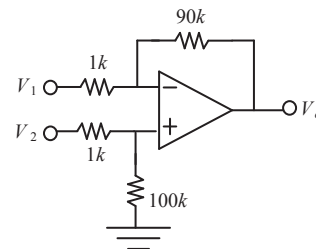
LEVEL 3

1. For good stabilized biasing of the transistor of the CE amplifier of figure, we should have



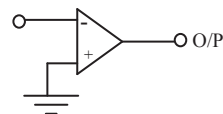
- (a) $(R_E/R_B) \ll 1$ (b) $(R_E/R_B) \gg 1$
(c) $(R_B/R_E) \ll h_{ie}$ (d) $(R_B/R_E) \gg h_{ie}$

2. The CMRR of the differential amplifier of figure is equal to



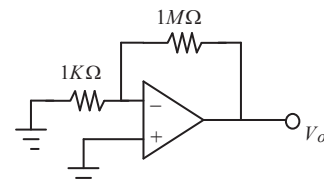
- (a) ∞ (b) 0
(c) 900 (d) 1800

3. If the input to the circuit of figure is sine wave, the output will be



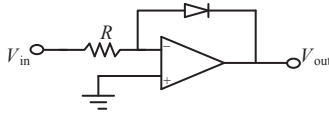
- (a) A half-wave rectified sine wave
(b) A full wave rectified sine wave
(c) A triangular wave
(d) A square wave

4. An op-amp has an offset voltage of 1 mV and is ideal in all other respects. If this op-amp is used in the circuit shown in figure, the output voltage will be (select the nearest value)

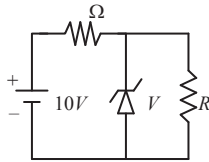


- (a) 1 mV (b) 1 V
(c) ± 1 V (d) 0 V

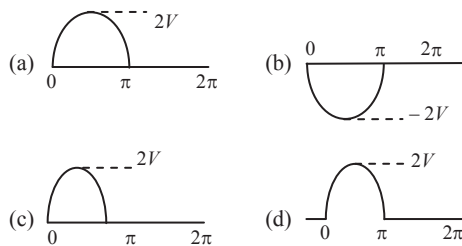
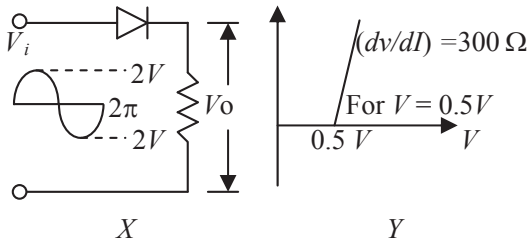
5. The circuit of the figure uses an ideal op-amp. For small positive values of V_{in} , the circuit works as



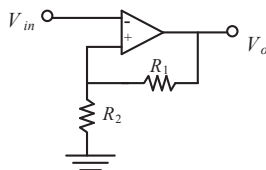
- (a) A half-wave rectifier
(b) A differentiator
(c) A logarithmic amplifier
(d) An exponential amplifier
6. The 6 V zener diode shown in figure has zero zener resistance and a knee current of 5 mA. The minimum value of R so that the voltage across it does not fall below 6 V is



- (a) 1.2K ohms
(b) 80 ohms
(c) 50 ohms
(d) 0 ohms
7. Consider the circuit shown in figure X. If the diode used here has the V-I characteristic as in figure Y then the output wave form v_o is

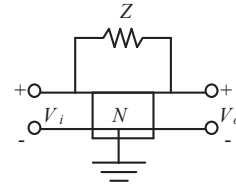


8. The circuit shown in the figure, is that of



- (a) A non-inverting amplifier
(b) An inverting amplifier
(c) An oscillator
(d) A Schmitt trigger

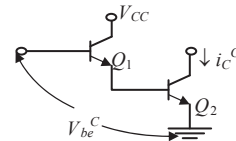
9. In the circuit shown in figure, N is a finite gain amplifier with a gain of k , a very large input impedance, and a very low output impedance. The input impedance of the feedback amplifier with the feedback impedance Z connected as shown will be



- (a) $Z(1 - 1/k)$
(b) $Z(1 - k)$
(c) $Z/(k - 1)$
(d) $Z/(1 - k)$

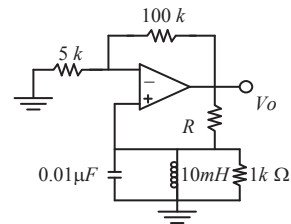
10. A Darlington stage is shown in the figure. If the transconductance of Q_1 is g_{m1} and that of Q_2 is G_{m2} , then the overall trans-conductance

$$g_{mc} = \Delta i_C \frac{C}{C} \text{ is given by}$$



- (a) g_{m1}
(b) $0.5 g_{m1}$
(c) g_{m2}
(d) $0.5 g_{m2}$

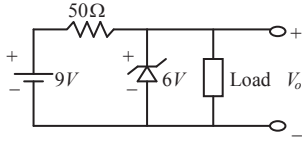
11. Value of R in the oscillator circuit shown in the figure, is so chosen that it just oscillates at an angular frequency of ω . The value of ω and the required value of R will respectively be



- (a) $10^5 \text{ rad/sec}, 2 \times 10^4 \Omega$
(b) $2 \times 10^4 \text{ rad/sec}, 2 \times 10^4 \Omega$
(c) $2 \times 10^4 \text{ rad/sec}, 10^5 \Omega$
(d) $10^5 \text{ rad/sec}, 10^5 \Omega$

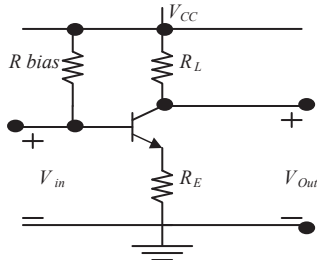
12. A zener diode in the circuit shown in figure has a knee current of 5 mA, and an maximum allowed power dissipation of 300 mW. What is the minimum and maximum load currents

that can be drawn safely from the circuit, keeping the output voltage V_o constant at 6 V?



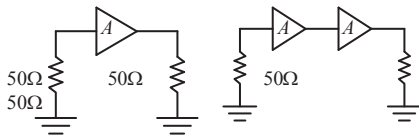
- (a) 0 mA, 180 mA (b) 5 mA, 110 mA
(c) 10 mA, 55 mA (d) 60 mA, 180 mA

13. In the BJT amplifier in figure, the transistor is biased in the forward active region. Putting a capacitor across R_E will



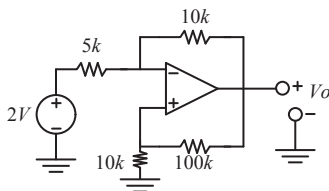
- (a) Decrease the voltage gain and decrease the input impedance
(b) Increase the voltage gain and decrease the input impedance
(c) Decrease the voltage gain and increase the input impedance
(d) Increase the voltage gain and increase the input impedance

14. An amplifier A has 6 dB gain and 50 Ω input and output impedances. The noise figure of this amplifier as shown in the figure is 3 dB cascade of two such amplifiers as in figure. Will have a noise figure of



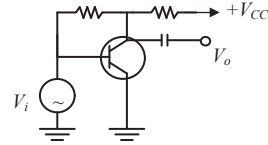
- (a) 6 dB (b) 8 dB
(c) 12 dB (d) None of the above

15. The output voltage V_o of the circuit shown in is



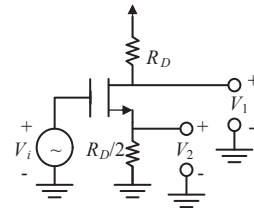
- (a) -4 V (b) 6 V
(c) 5 V (d) -5.5 V

16. The circuit of figure is an example of feedback of the following type



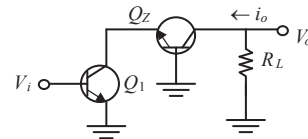
- (a) current series (b) current shunt
(c) voltage series (d) voltage shunt

17. In the MOSFET amplifier of figure, the signal output V_1 and V_2 obey the relationship



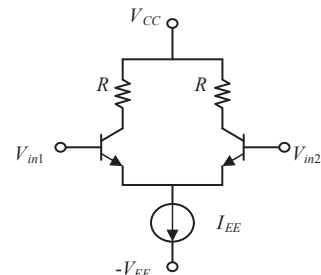
- (a) $V_1 = [V_2/2]$ (b) $V_1 = -[V_2/2]$
(c) $V_1 = +2V_2$ (d) $V_1 = -2V_2$

18. In the cascade amplifier shown in figure, if the common-emitter stage (Q_1) has a trans-conductance g_{m1} and the common base stage (Q_2) has a trans-conductance g_{m2} then the overall trans conductance ($g_m = i_o/v_i$) of the cascades amplifier is



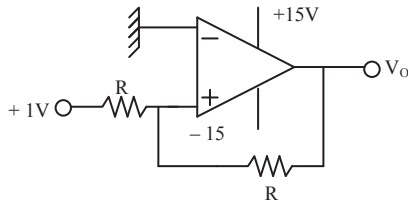
- (a) g_{m1} (b) g_{m2}
(c) $g_{m1}/2$ (d) $g_{m2}/2$

19. In the differential amplifier of figure if the source resistance of the current source I_{EE} is infinite, then the common-mode gain is



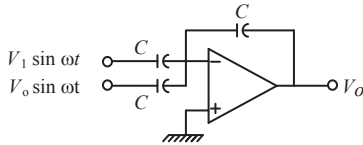
- (a) Zero (b) Infinite
(c) Indeterminate (d) $\frac{V_{in1} + V_{in2}}{2V_T}$

20. In the circuit of figure V_o is



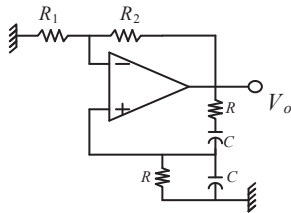
- (a) -1 V (b) 2 V
(c) +1 V (d) +15 V

21. If the op-amp in figure is ideal, then v_o is



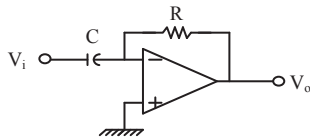
- (a) zero (b) $(V_1 - V_2) \sin \omega t$
(c) $-(V_1 + V_2) \sin \omega t$ (d) $(V_1 + V_2) \sin \omega t$

22. The configuration of figure is



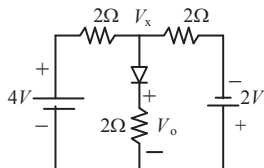
- (a) Precision integrator
(b) Hartley oscillator
(c) Butter-worth high pass filter
(d) Wien-bridge oscillator

23. Assume that the op-amp of figure is ideal. If v_i is a triangular wave, then v_o will be



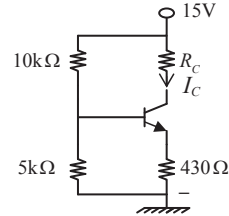
- (a) square wave (b) triangular wave
(c) parabolic wave (d) sine wave

24. For the circuit in figure the voltage v_o is



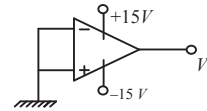
- (a) 2 V (b) 1 V
(c) -1 V (d) None of the above

25. In the circuit of figure, assume that the transistor is in active region. It has a large β and its base-emitter voltage is 0.7 V. The value of I_C is



- (a) Indeterminate since R_C is not given
(b) 1 Ma
(c) 5 mA
(d) 10 mA

26. If the op-amp in figure has an input offset voltage of 5mV and open-loop voltage gain of 10,000 then v_o will be



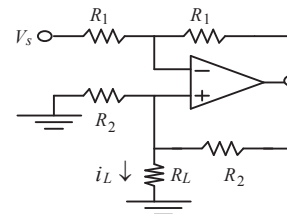
- (a) 0 V
(b) 5 mV
(c) +15 V or -15 V
(d) +50 V or -50 V

27. For the ring oscillator shown in figure, the propagation delay of each inverter is 100 pico second. What is the fundamental frequency of the oscillator output?



- (a) 10 MHz (b) 100 MHz
(c) 1 GHz (d) 2 GHz

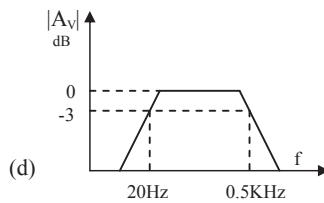
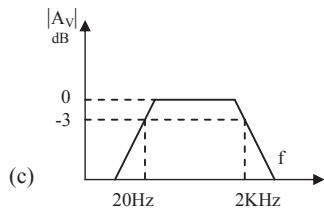
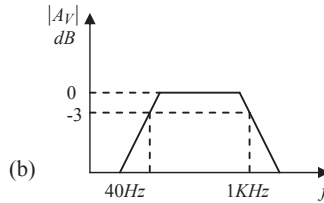
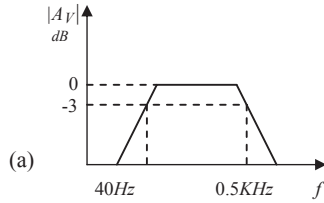
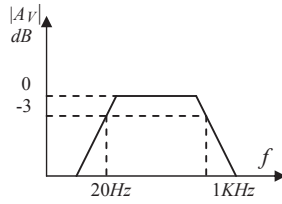
28. In the op-amp circuit given in figure, the load current i_L is



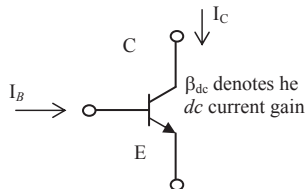
- (a) $-V_s/R_2$ (b) V_s/R_2
(c) $-V_s/R_L$ (d) V_s/R_L

29. Three identical RC-coupled transistor amplifiers are cascaded. If each of the amplifier has frequency response

as shown in figure, the overall frequency response in as given in



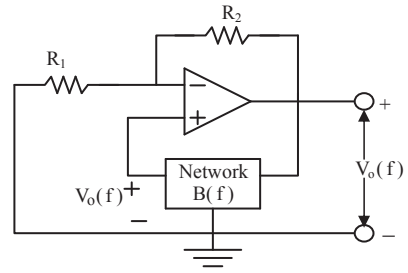
30. If the transistor in figure is in saturation, then



- (a) I_c is always equal to $\beta_{dc} I_B$
- (b) I_c is always equal to $-\beta_{dc} I_B$
- (c) I_c is greater than or equal to $\beta_{dc} I_B$
- (d) I_c is less than or equal to $\beta_{dc} I_{B1}$

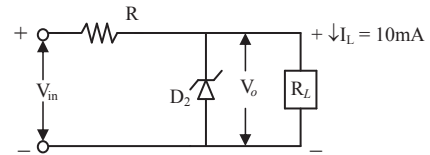
31. The circuit in figure employs positive feedback and is intended to generate sinusoidal oscillation. If at a frequency f_0 , $B(f) =$

$[V_f(f)/V_o(f)] = (1/6) \angle 0^\circ$, then to sustain oscillation at this frequency



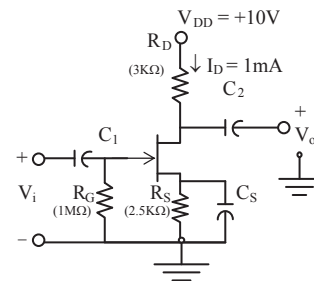
- (a) $R_2 = 5R_1$
- (b) $R_2 = 6R_1$
- (c) $R_2 = (R_1/6)$
- (d) $R_2 = (R_1/5)$

32. A zener diode regulator in figure is to be designed to meet the specifications: $I_L = 10 \text{ mA}$, $V_o = 10 \text{ V}$ and V_{in} varies from 30 V to 50 V. The zener diode has $V_z = 10 \text{ V}$ and I_{zk} (knee current) = 1mA. For satisfactory operation



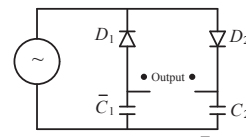
- (a) $R \leq 1800 \Omega$
- (b) $2000 \Omega \leq R \leq 2200 \Omega$
- (c) $3700 \Omega \leq R \leq 4000 \Omega$
- (d) $R > 4000 \Omega$

33. The voltage gain $A_v = (V_o/V_i)$ of the JEET amplifier shown in the figure is



- (a) +18
- (b) -18
- (c) +6
- (d) -6

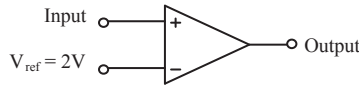
34. The circuit shown in the figure is best described as a



- (a) Bridge rectifier
- (b) Ring modulator
- (c) Frequency discriminatory
- (d) Voltage doubler

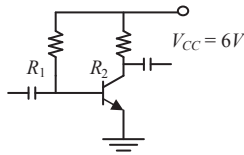
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35. If the input to the ideal comparator shown in the figure is a sinusoidal signal of 8V (peak to peak) without any DC component, then the output of the comparator has a duty cycle of



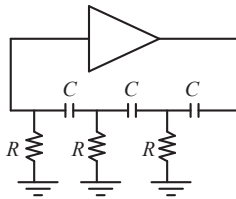
- (a) $\frac{1}{2}$ (b) $\frac{1}{3}$
(c) $\frac{1}{6}$ (d) $\frac{1}{12}$

36. In the amplifier circuit shown in the figure the values of R_1 and R_2 are such that the transistor is operating at $V_{CE} = 3\text{ V}$ and $I_C = 1.5\text{ mA}$ when its β is 150. For a transistor with β of 200, the operating point (V_{CE} , I_C) is



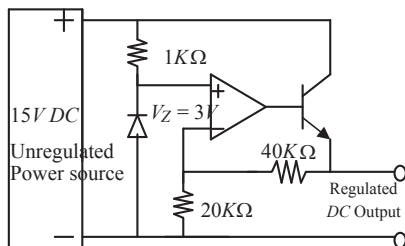
- (a) 2V, 2 mA (b) 3V, 2mA
(c) 4V, 2mA (d) 4V, 1mA

37. The oscillator circuit shown in the figure has an ideal inverting amplifier. Its frequency of oscillation (in Hz) is



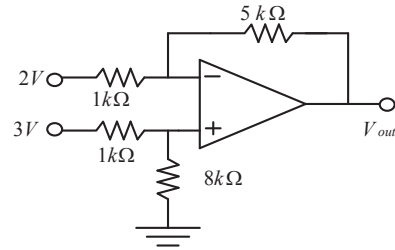
- (a) $\frac{1}{(2\pi\sqrt{6}RC)}$ (b) $\frac{1}{(2\pi RC)}$
(c) $\frac{1}{(\sqrt{6}RC)}$ (d) $\frac{1}{(6(2\pi RC))}$

38. The output voltage of the regulated power supply shown in the figure is



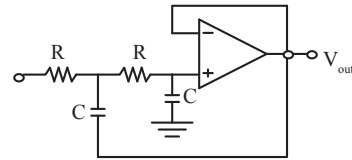
- (a) 3 V (b) 6 V
(c) 9 V (d) 12 V

39. If the op-amp in figure is ideal, the output voltage V_i will be equal to



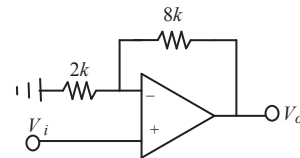
- (a) 1 V (b) 6 V
(c) 14 V (d) 17 V

40. The circuit in figure is a



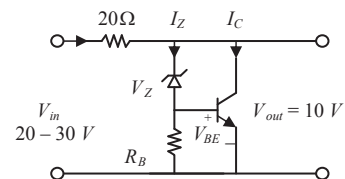
- (a) low-pass filter
(b) high-pass filter
(c) band-pass filter
(d) band-reject filter

41. The op-amp of figure has a very poor open loop voltage gain of 45 but is otherwise ideal. The gain of the amplifier equals



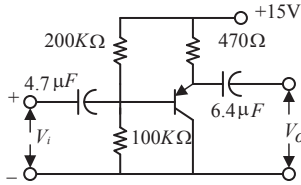
- (a) 5 (b) 20
(c) 4 (d) 4.5

42. The transistor shunt regulator shown in the figure has a regulated output voltage of 10 V, when the input varies from 20 V to 30 V. The relevant parameters for the zener diode and the transistor are: $V_Z = 9.5\text{ V}$, $V_{BE} = 0.5\text{ V}$, $\beta = 99$. Neglect the current through R_B . Then the maximum power dissipated in the zener diode (P_Z) and the transistor (P_T) are



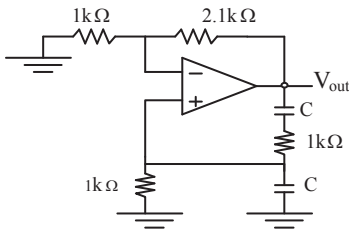
- (a) $P_Z = 75\text{ mW}$, $P_T = 7.9\text{ W}$
(b) $P_Z = 85\text{ mW}$, $P_T = 8.9\text{ W}$
(c) $P_Z = 95\text{ mW}$, $P_T = 9.9\text{ W}$
(d) $P_Z = 115\text{ mW}$, $P_T = 11.9\text{ W}$

43. For the amplifier circuit of figure the transistor a β of 800. The mid-band voltage gain V_o/V_i , of the circuit will be



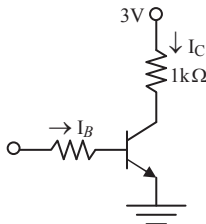
- (a) 0
(b) <1
(c) = 1
(d) 800

44. The value of C required for sinusoidal oscillations of frequency 1 KHz in the circuit of figure is



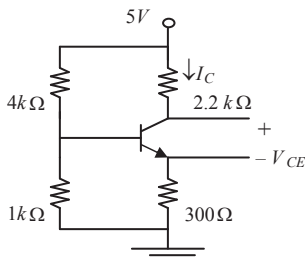
- (a) $1/2\pi \mu\text{F}$
(b) $2\pi \mu\text{F}$
(c) $1/2\pi \sqrt{6} \mu\text{F}$
(d) $2\pi \sqrt{6} \mu\text{F}$

45. Assuming $V_{CEsat} = 0.2 \text{ V}$ and $\beta = 50$, the minimum base current (I_B) required to drive the transistor in figure to a saturation is



- (a) 56 μA
(b) 140 mA
(c) 60 μA
(d) 3 mA

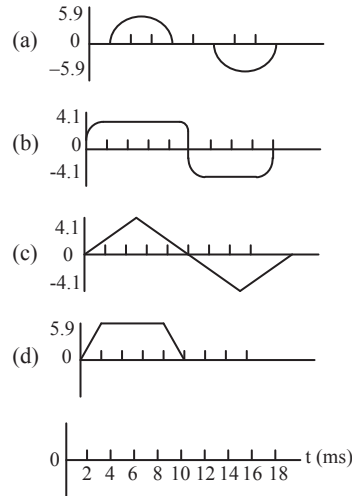
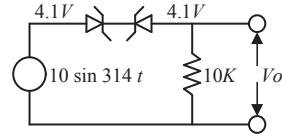
46. Assuming that the β of the transistor is extremely large and $V_{BE} = 0.7 \text{ V}$, I_c and V_{CE} in the circuit shown in figure are



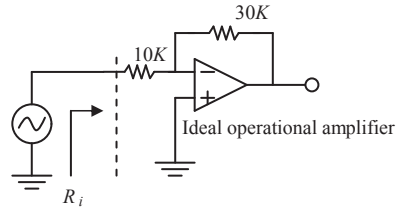
- (a) $I_c = 1 \text{ mA}$, $V_{CE} = 4.7 \text{ V}$
(b) $I_c = 0.5 \text{ mA}$, $V_{CE} = 3.75 \text{ V}$

- (c) $I_c = 1 \text{ mA}$, $V_{CE} = 2.5 \text{ V}$
(d) $I_c = 0.5 \text{ mA}$, $V_{CE} = 3.9 \text{ V}$

47. The wave-shape of V_o in figure will be

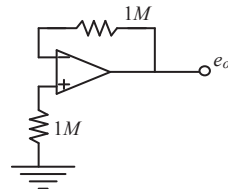


48. The input resistance R_i of the amplifier shown in the figure is



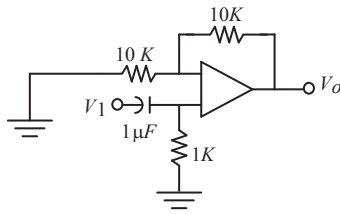
- (a) $[30/4] \text{ k}\Omega$
(b) 10 k Ω
(c) 40 k Ω
(d) infinite

49. The voltage e_o indication in the figure has been measured by an ideal voltmeter which of the following can be calculated?

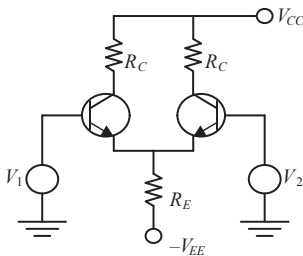


- (a) Bias current of the inverting input only
(b) Bias current of the inverting and non-inverting inputs only
(c) Input offset current only
(d) Both the bias currents and the input offset current

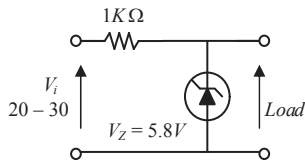
50. The op-amp circuit shown in the figure is a filter. The type of filter and its cutoff frequency are respectively



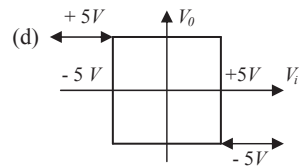
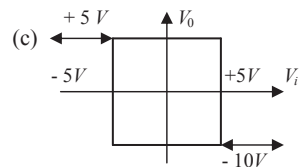
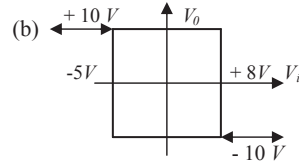
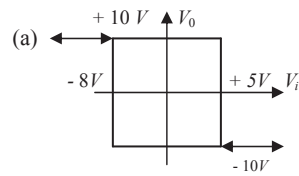
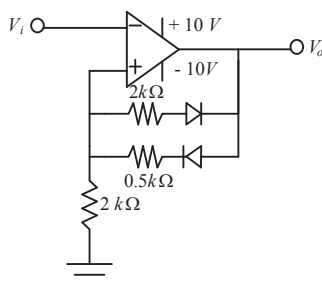
- (a) High pass, 1000 rad/sec
 (b) Low pass, 1000 rad/sec
 (c) High pass, 10000 rad/sec
 (d) Low pass, 10000 rad/sec
51. In an ideal differential amplifier shown in the figure, a large value of (R_E)



- (a) Increase both the differential and common-mode gains
 (b) Increases the common-mode gain only
 (c) Decreases the differential-mode gain only
 (d) Decreases the common-mode gain only
52. The zener diode in the regulator circuit shown in the figure has a zener voltage of 5.8 Volts and a zener knee current of 0.5 mA. The maximum load current drawn from this circuit ensuring proper functioning over the input voltage range between 20 and 30 volts, is

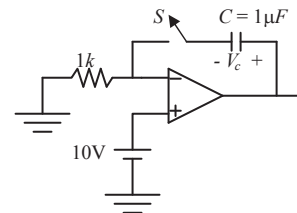


- (a) 23.7 mA
 (b) 14.2 mA
 (c) 13.7 mA
 (d) 24.2 mA
53. Given the ideal operational amplifier circuit shown in the figure, indicate the correct transfer characteristic assuming ideal diodes with zero cut-in voltage



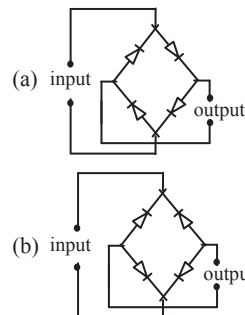
54. For the circuit shown in the following figure, the capacitor C is initially uncharged.

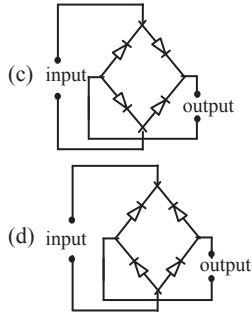
At $t = 0$, the switch S is closed. The voltage V_c across the capacitor at $t = 1$ millisecond is



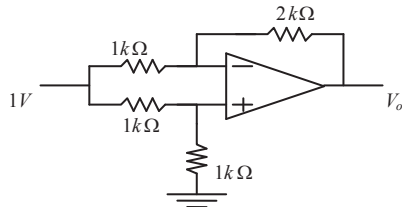
In the figure shown above, the op-amp is supplied with $\pm 15V$

- (a) 0 Volt
 (b) 6.3 Volts
 (c) 9.45 Volts
 (d) 10 Volts
55. The correct full wave rectifier circuit is



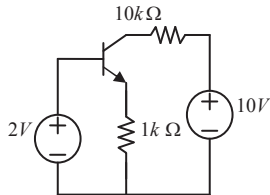


56. For the op-amp circuit shown in the figure, V_o is



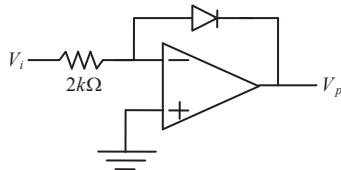
- (a) -2 V (b) -1 V
(c) -0.5 V (d) 0.5 V

57. For the BJT circuit shown, assume that the β of the transistor is very large and $V_{BE} = 0.7\text{ V}$. The mode of operation of the BJT is



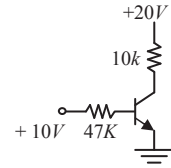
- (a) Cutoff (b) Saturation
(c) Normal active (d) Reverse active

58. In the Op-Amp circuit shown, assume that the diode current follows the equations $I = I_s e^{(V/V_T)}$. For $V_i = 2\text{ V}$, $V_o = V_{o1}$, and $V_i = 4\text{ V}$, $V_o = V_{o2}$. The relationship between V_{o1} and V_{o2} is



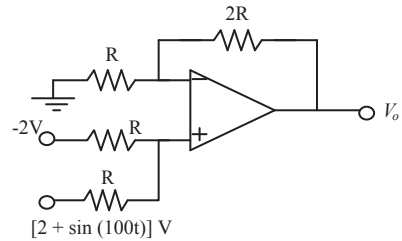
- (a) $V_{o2} = \sqrt{2} V_{o1}$
(b) $V_{o2} = e^2 V_{o1}$
(c) $V_{o2} = V_{o1} \ln 2$
(d) $V_{o1} - V_{o2} = V_T \ln 2$

59. In the transistor circuit shown in the figure below, collector-to-ground voltage is $+20\text{ V}$. Which of the following is the probable cause of error?



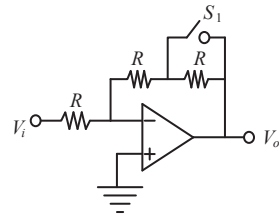
- (a) Collector-emitter terminals shorted
(b) Emitter to ground connection open
(c) $10\text{ K}\Omega$ resistor open
(d) collector-base terminals shorted

60. non-inverting op-Amp amplifier is shown in the figure below. The output voltage V_o is



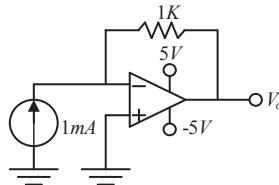
- (a) $(3/2) \sin(100t)$ (b) $3 \sin(100t)$
(c) $2 \sin(100t)$ (d) None of the above

61. Let the magnitude of the gain in the inverting op-amp amplifier circuit shown in the figure below, be x with switch S_1 open. When the switch S_1 is closed, the magnitude of gain becomes



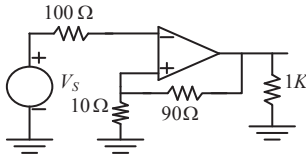
- (a) $x/2$ (b) $-x$
(c) $2x$ (d) $-2x$

62. The circuit shown in the figure uses an ideal op amp working with $+5\text{ V}$ and -5 V power supplies. The output voltage V_o is equal to



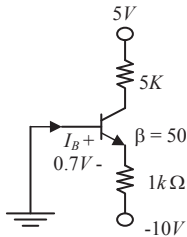
- (a) $+5\text{ V}$ (b) -5 V
(c) $+1\text{ V}$ (d) -1 V

63. The feedback factor for the circuit shown in the figure is



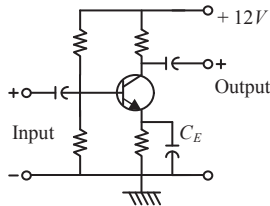
- (a) 9/100 (b) 9/10
(c) 1/9 (d) 1/10

64. In the circuit of figure, the value of the base current I_B will be



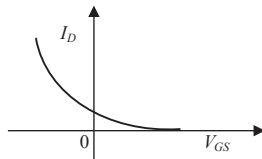
- (a) 0.0 micro amperes
(b) 18.2 micro amperes
(c) 26.7 micro amperes
(d) 40.0 micro amperes

65. In the single-stage transistor amplifier circuit shown in the figure, the capacitor C_E is removed. Then, the ac small-signal midband voltage gain of the amplifier



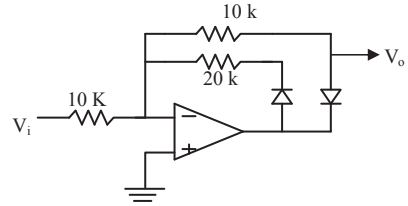
- (a) Increases (b) Decreases
(c) Is unaffected (d) Drops to zero

66. The variation of drain current with gate-to-source voltage (I_D - V_{GS} characteristic) of a MOSFET is shown in the figure. The MOSFET is

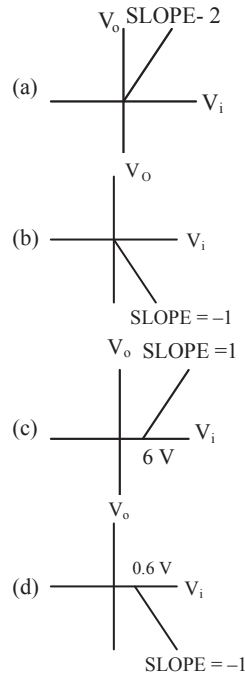


- (a) An n-channel depletion mode device
(b) An n-channel enhancement mode device
(c) A p-channel depletion mode device
(d) A p-channel enhancement mode device

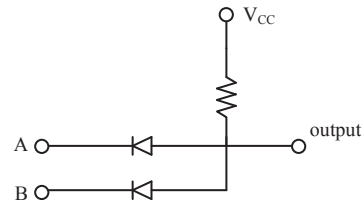
67. The cut-in voltage of the diodes in the rectifier is shown below is 6V



Identify the correct output input characteristic. (V_o vs V_i)

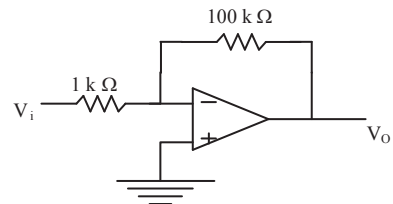


68. The diode circuit shown in the figure function as



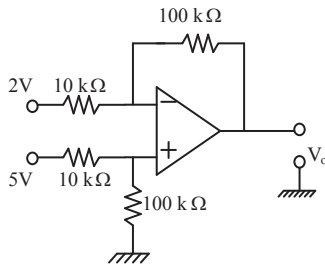
- (a) AND gate (b) OR gate
(c) NAND gate (d) NOR gate

69. The input resistance of the op-amp circuit shown in the figure is



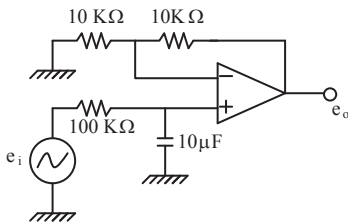
- (a) 100 kΩ (b) 99 kΩ
(c) 1 kΩ (d) 101 kΩ

70. The output voltage (V_o) of the circuit shown in the figure is



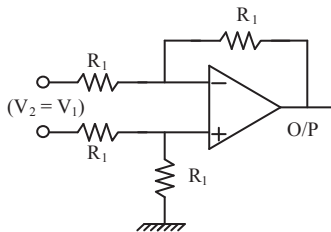
- (a) -20 V (b) 20 V
(c) -30 V (d) 30 V

71. In the circuit shown in the figure, if $e_i = \sin t$, the voltage e_o is



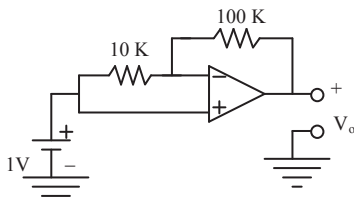
- (a) $\sqrt{2} \sin [t - (\pi/4)]$
(b) $\{1/\sqrt{2}\} \sin [t + (\pi/4)]$
(c) $\{1/\sqrt{2}\} \sin [t - (\pi/4)]$
(d) $\sqrt{2} \sin [t + (\pi/4)]$

72. The differential input resistance of the circuit shown in the figure is



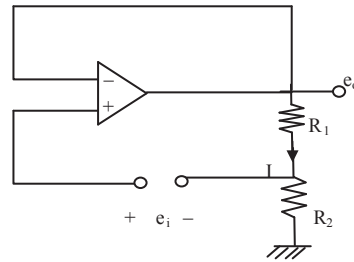
- (a) R_1 (b) $R_1/2$
(c) $2R_1$ (d) R_f

73. In the op-amp circuit shown in the figure, the output voltage V_o is equal to



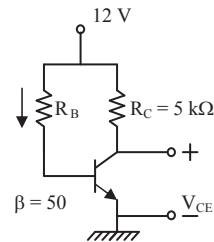
- (a) 11 V (b) -10 V
(c) 9 V (d) 1 V

74. Pick up the correct relationship for the circuit shown in the figure



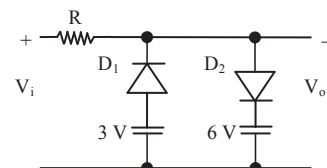
- (a) $e_o = e_i$ (b) $e_o = \frac{R_2}{R_1} e_i$
(c) $1 = \frac{e_i}{R_2}$ (d) $1 = \frac{e_i}{R_1}$

75. For a silicon BJT shown in the figure find R_B to establish $V_{CE} = 2V$, Assume $V_{BE} = 0.7V$



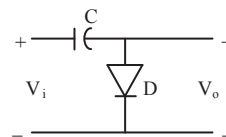
- (a) 283 KΩ (b) 107 KΩ
(c) 200 KΩ (d) 242 KΩ

76. In the circuit shown in the figure V_i is 4 V. Assuming the diodes to be ideal, V_o is



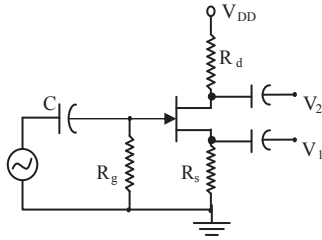
- (a) 3 V (b) 4 V
(c) 4.5 V (d) 6 V

77. The input voltage, v_i is $4 + 3 \sin \omega t$. assuming all elements to be ideal, the average of the output voltage v_o in figure is



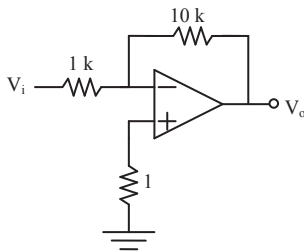
- (a) -3 V (b) +3 V
(c) -7 V (d) +7 V

78. In the JFET amplifier circuit shown in the figure, the signal outputs V_1 and V_2 are related as



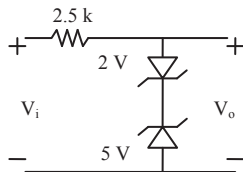
- (a) $V_2 = \frac{R_d}{R_c} V_1$ (b) $V_2 = -\frac{R_d}{R_c} V_1$
(c) $V_2 = \frac{R_c}{R_d} V_1$ (d) $V_2 = -\frac{R_c}{R_d} V_1$

79. The op-amp in the amplifier circuit shown in the figure has an offset voltage of 10 mV and it is ideal otherwise. If V_i is zero, the output voltage V_o is



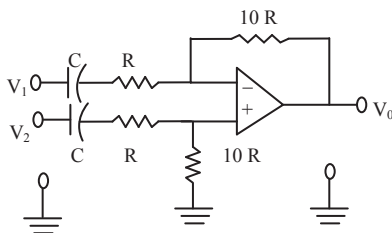
- (a) 0 (b) 10 mV
(c) 100 mV (d) 110 mV

80. For a sinusoidal input 50 V amplitude, the circuit shown in the figure can be used as



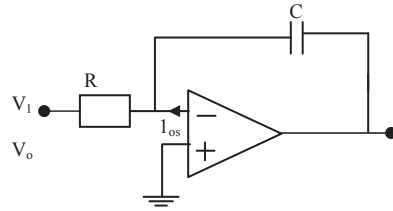
- (a) Regulated dc power supply
(b) Square wave generator
(c) Half wave rectifier
(d) Full wave rectifier

81. In figure input offset voltage of the operational amplifier is 2 mV. The output dc-error voltage is



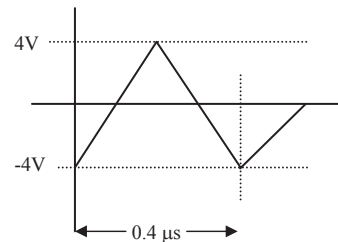
- (a) 0 (b) 2 mV
(c) 11 mV (d) 22 mV

82. An integrator circuit is shown in the figure. The op-amp is of type 741 and has an input offset current i_{os} of 1 μ A. C is 1 μ F and R is 1 M Ω . If the input V_i is a 1 kHz. Square wave of 1V peak to peak, the output V_o , under steady state condition, will be



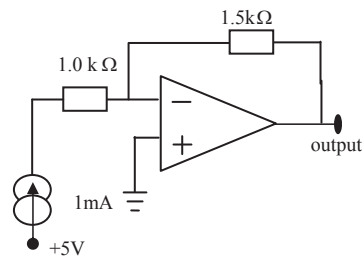
- (a) A square wave of 1 V peak to peak
(b) A triangular wave of 1 V peak to peak
(c) Positive supply voltage + V_{cc}
(d) Negative supply voltage - V_{cc}

83. The output of an op-amp whose input is a 2.5 MHz square wave is shown in figure. The slew rate of the Ops- amp is



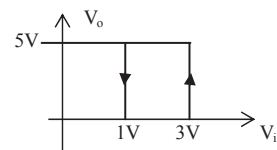
- (a) 0.8 V/ μ s (b) 8.0 V/ μ s
(c) 20.0 V/ μ s (d) 40.0 V/ μ s

84. The op-amp and the 1 mA current source in the circuit of figure are ideal. The output of the op-amp is



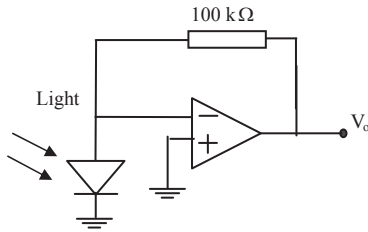
- (a) -1.5 mA (b) -1.5 V
(c) -7.5 v (d) +1.5

85. The input output characteristics of a Schmitt trigger is given in figure. The noise margin of the Schmitt trigger is

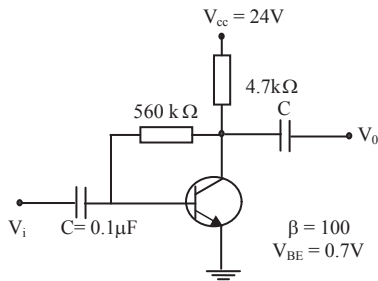


- (a) 1 V (b) 2 V
(c) 3 V (d) 4 V

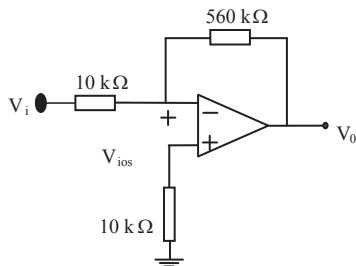
86. A photo-detector circuit is given in figure. The photo-diode has an active area of 10^{-2} cm^2 and sensitivity of 0.55 A/W . When light of intensity 10 mW/cm^2 falls on the photo-diode, the output V_o is



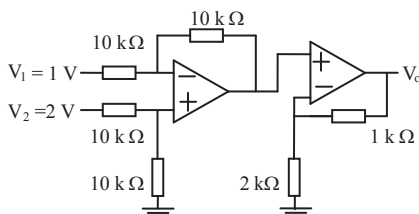
- (a) 10.1 V (b) 5.5 V
(c) -5.5 V (d) -10.1 V
87. A transistor amplifier circuit is shown in the figure. The quiescent collector current, rounded off to first decimal, is



- (a) 2.6 mA (b) 2.3 mA
(c) 2.1 mA (d) 2.0 mA
88. The op-amp used in the inverting amplifier shown in the figure has an equivalent input offset voltage V_{ios} of 5 mV. The output offset voltage is

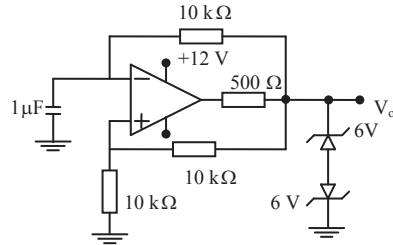


- (a) 5 mV (b) 280 mV
(c) 285 mV (d) 560 mV
89. In the circuit shown in the figure the op-amps used are ideal. The output V_o is



- (a) 3.0 V (b) 1.5 V
(c) 1.0 V (d) 0.5 V

90. The circuit shown in the figure is that of a waveform generator. Assuming ideal devices, and $\pm 12 \text{ V}$ supply the output V_o is a



- (a) Triangular wave of period 120 ms and amplitude $\pm 6 \text{ V}$
(b) Square wave of period 60 ms and amplitude $\pm 6 \text{ V}$
(c) Square wave of period 120 ms and amplitude $\pm 6 \text{ V}$
(d) Square wave of period 60 ms and amplitude $\pm 12 \text{ V}$
91. An operational amplifier has a slew rate of $100 \text{ V/microsecond}$. For a frequency of 10 MHz , the maximum (peak) value of the sine-wave output voltage will be
- (a) 100 V (b) $50/\pi \text{ V}$
(c) 10 V (d) 5 V
92. An amplifier has an input power of 2 microwatts. The power gain of the amplifier is 60 dB. The output power will be
- (a) 6 microwatts (b) 120 microwatt
(c) 2 mill watts (d) 2 watts
93. In which one of the following transistor configuration, is the input impedance least dependent on the load resistance?
- (a) CE
(b) CB
(c) CE
(d) CE with un-bypassed emitter resistance
94. A BJT has CE parametres as given below
- $$h_{ie} = 5 \text{ k ohms}, \quad h_{re} = 10^{-5}$$
- $$h_{fe} = 100, \quad h_{oe} = 1.5 \times 10^{-5} \text{ mho}$$
- the value of h_{ib} for CB configuration is
- (a) 10^{-5} ohm (b) 49.5 ohms
(c) 5000 ohms (d) 10^5 ohms
95. In an operational amplifier circuit, the maximum frequency for the undistorted output is 100 kHz for 10 volts $p-p$ output because of the finite slew rate of the OPAMP. The maximum frequency for undistorted output of 5 volts $p-p$
- (a) Will be approximately 100 kHz
(b) Will be less than 100 kHz
(c) Will be more than 100 kHz
(d) Cannot be deter mind from the given data
96. When n_e and n_h are the electron and hole densities, μ_e and μ_h are the carries motilities the Hall coefficient is positive when
- (a) $n_h \mu_h > n_e \mu_e$ (b) $n_h \mu_h^2 > n_e \mu_e^2$
(c) $n_h \mu_h < n_e \mu_e$ (d) $n_h \mu_h^2 < n_e \mu_e^2$

97. Quantum effects have to be taken into account in determining the properties of materials if

- (a) $E_F = 3/2 KT$ (b) $E_F < 3/2 KT$
(c) $E_F > 3/2 KT$ (d) $E_F \gg 3/2 KT$

98. A differential amplifier has a differential gain of 20,000. CMRR = 80 dB. The common mode gain is given by

- (a) 2 (b) 1
(c) $\frac{1}{2}$ (d) 0

99. For the junction transistor, which of the following relation is true?

- (a) $\alpha = \frac{\beta}{1-\beta}$ (b) $\alpha = \beta(1+\beta)$
(c) $\beta = \frac{\alpha}{1-\alpha}$ (d) $\beta = \frac{\alpha}{1+\alpha}$

100. For a UJT if

R_1 = resistance from emitter to the base 1

R_2 = resistance from emitter to the base 2

And $R_{BB} = R_1 + R_2$ then the intrinsic stand off ratio (η) is

- (a) R_1/R_2 (b) R_1/R_{BB}
(c) R_2/R_1 (d) R_2/R_{BB}

101. In the Fermi-Dirac statistics, the probability of electron occupation of an energy level equal to the Fermi level is

- (a) 0 (b) 0.25
(c) 0.5 (d) 1.0

102. If P_r is the rate at which carriers are produced by light in a photo-diode, τ is the average life time for the newly created carries, T_i is the average transit time for carries to reach the Ohmic contacts of the diode and 'e' is the electronic charge, then the steady-stage photo-current will be given by

- (a) $i = \frac{2e P_r \tau}{T_i}$ (b) $i = \frac{e P_r \tau}{2T_i}$
(c) $i = \frac{e P_r \tau}{T_i}$ (d) $i = \frac{e P_r \tau}{3T_i}$

103. In an ideal junction transistor, the impurity concentration in the emitter (E), base (B) and collector (C) are such that

- (a) $E > C > B$ (b) $B > C > E$
(c) $C > E > B$ (d) $C = E = B$

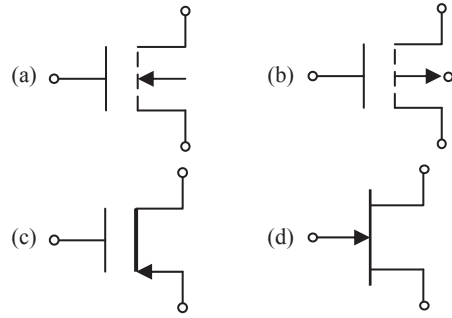
104. The collector to emitter cutoff current (I_{CEO}) of a transistor is related to collector to base cutoff current (I_{CBO}) as (α is the CB current gain of the transistor)

- (a) $I_{CEO} = I_{CBO}$ (b) $I_{CEO} = \alpha I_{CBO}$
(c) $I_{CEO} = \frac{I_{CBO}}{1-\alpha}$ (d) $I_{ECO} = \frac{I_{CBO}}{1-\alpha}$

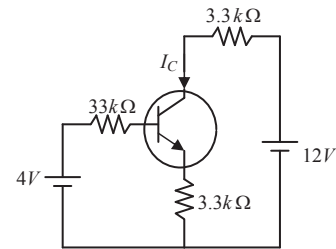
105. The drain-source output V-I characteristics of an n-channel depletion FET has

- (a) $I_{DS} = 0$ at $V_{GS} = 0$
(b) I_{DS} = positive maximum at $V_{GS} = 0$
(c) I_{DS} = negative maximum at $V_{GS} = 0$
(d) I_{DS} independent of V_{GS}

106. An enhancement type n-channel MOSFET is represented by the symbol

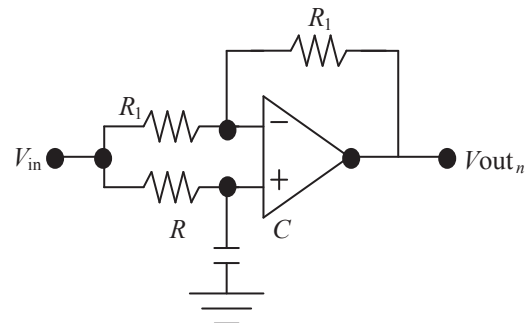


107. In the circuit assume that the transistor has $h_{FE} = 99$ and $V_{BE} = 0.7$. The value of collector I_C of the transistor is approximately



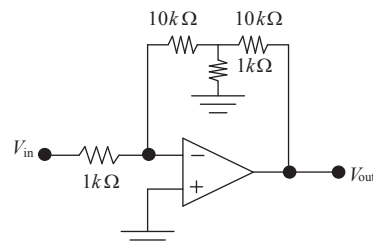
- (a) $[3.3/3.3]$ mA (b) $[3.3/(3.3 + .33)]$ mA
(c) $[3.3/33]$ mA (d) $[3.3/(33 + 3.3)]$ mA

108. For the circuit with an ideal operational amplifier, the maximum phase shift of the output V_{out} with reference to the input V_{in} is



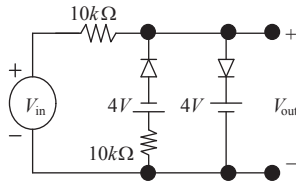
- (a) 0° (b) -90°
(c) $+90^\circ$ (d) $\pm 180^\circ$

109. Assuming operational amplifier to be ideal, the gain V_{out}/V_{in} for the circuit shown in the figure is

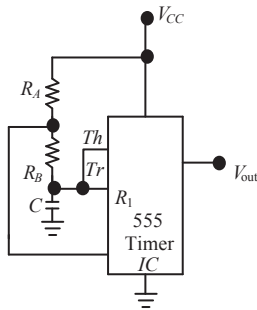


- (a) -1 (b) -20
(c) -100 (d) -120

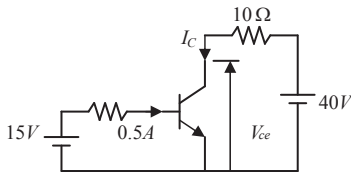
110. A voltage signal $10 \sin \omega t$ is applied to the circuit with ideal diodes, as shown in the figure. The maximum, and minimum values of the output waveform V_{out} of the circuit are respectively



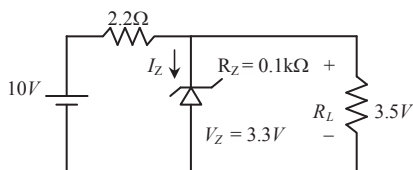
- (a) +10 V and -10 V (b) +4 V and -4 V
(c) +7 V and -4 V (d) +4 V and -7 V
111. The circuit of figure shows a 555 Timer IC connected as an astable multivibrator. The value of the capacitor C is 10 nF. The value of the resistors R_A and R_B for a frequency of 10 kHz and a duty cycle of 0.75 for the output voltage waveform are



- (a) $R_A = 3.62 \text{ k}\Omega$, $R_B = 3.62 \text{ k}\Omega$
(b) $R_A = 3.62 \text{ k}\Omega$, $R_B = 7.25 \text{ k}\Omega$
(c) $R_A = 7.25 \text{ k}\Omega$, $R_B = 3.62 \text{ k}\Omega$
(d) $R_A = 7.25 \text{ k}\Omega$, $R_B = 7.25 \text{ k}\Omega$
112. In the circuit shown in the figure the current gain (β) of the ideal transistor is 10. The operating point of the transistor (V_{ce} , I_c) is

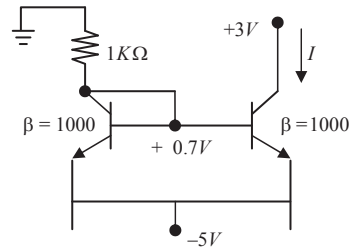


- (a) (40 V, 4A) (b) (40V, 5A)
(c) (0V, 4A) (d) (15V, 4A)
113. The current through the Zener diode in figure



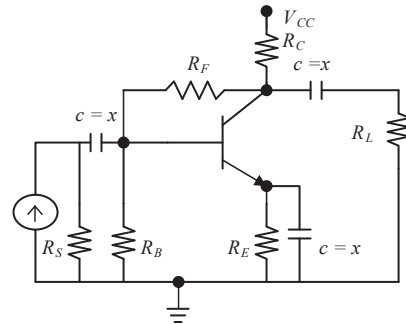
- (a) 33 mA (b) 3.3 mA
(c) 2 mA (d) 0 mA

114. Two perfectly matched silicon transistors are connected as shown in figure. The value of the current I is



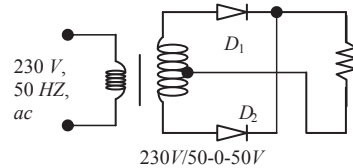
- (a) 0 mA (b) 2.3 mA
(c) 4.3 mA (d) 7.3 mA

115. The feedback used in the circuit shown in the figure can be classified as



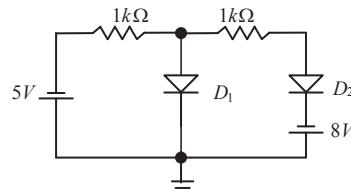
- (a) shunt-series feedback (b) shunt-shunt feedback
(c) series-shunt feedback (d) series-series feedback

116. The circuit in figure shows a full-wave rectifier. The input voltage is 230 V (rms) single-phase ac. The peak reverse voltage across the diodes D_1 and D_2 is



- (a) $100\sqrt{2} \text{ V}$ (b) 100 V
(c) $50\sqrt{2} \text{ V}$ (d) 50 V

117. Assuming that the diodes are ideal in figure. The current in diode D_1 is



- (a) 8 ma (b) 5 mA
(c) 0 mA (d) -3 mA

ANSWER KEYS

LEVEL 1

1. (b)	2. (c)	3. (a)	4. (a)	5. (d)	6. (d)	7. (b)	8. (b)	9. (d)	10. (b)
11. (a)	12. (b)	13. (b)	14. (a)	15. (d)	16. (d)	17. (a)	18. (a)	19. (b)	20. (a)
21. (c)	22. (b)	23. (c)	24. (d)	25. (d)	26. (b)	27. (c)	28. (b)	29. (d)	30. (d)
31. (b)	32. (c)	33. (a)	34. (d)	35. (c)	36. (c)	37. (c)	38. (b)	39. (b)	40. (d)
41. (b)	42. (c)	43. (d)	44. (a)	45. (c)	46. (c)	47. (c)	48. (b)	49. (b)	50. (d)
51. (a)	52. (b)	53. (a)	54. (b)	55. (b)	56. (a)	57. (d)	58. (c)	59. (d)	60. (b)
61. (c)	62. (b)	63. (d)	64. (a)	65. (a)	66. (b)	67. (c)	68. (b)	69. (d)	70. (a)
71. (d)	72. (a)	73. (b)	74. (b)	75. (d)	76. (d)	77. (a)	78. (c)	79. (b)	80. (c)
81. (c)	82. (b)								

LEVEL 2

1. (b)	2. (d)	3. (a)	4. (c)	5. (b)	6. (d)	7. (d)	8. (d)	9. (a)	10. (b)
11. (b)	12. (b)	13. (a)	14. (c)	15. (a)	16. (b)	17. (d)	18. (a)	19. (b)	20. (c)
21. (c)	22. (a)	23. (b)	24. (b)	25. (a)	26. (d)	27. (c)	28. (c)	29. (d)	30. (a)
31. (b)	32. (d)	33. (b)	34. (b)	35. (b)	36. (d)	37. (c)	38. (d)	39. (b)	40. (d)
41. (d)	42. (c)	43. (b)	44. (d)	45. (b)	46. (c)	47. (c)	48. (c)	49. (b)	50. (a)
51. (c)	52. (b)	53. (c)	54. (c)	55. (d)	56. (c)	57. (a)	58. (a)	59. (a)	60. (b)
61. (a)	62. (b)	63. (a)	64. (d)	65. (b)	66. (c)	67. (c)	68. (c)	69. (c)	70. (c)
71. (d)	72. (d)	73. (b)	74. (b)	75. (b)	76. (a)	77. (a)	78. (b)	79. (b)	80. (b)
81. (d)	82. (d)	83. (a)	84. (a)	85. (c)	86. (b)	87. (a)	88. (d)	89. (d)	90. (b)
91. (d)									

LEVEL 3

1. (b)	2. (c)	3. (d)	4. (c)	5. (c)	6. (b)	7. (c)	8. (d)	9. (d)	10. (a)
11. (a)	12. (c)	13. (b)	14. (d)	15. (d)	16. (d)	17. (c)	18. (a)	19. (a)	20. (d)
21. (c)	22. (d)	23. (a)	24. (b)	25. (d)	26. (c)	27. (c)	28. (a)	29. (a)	30. (d)
31. (a)	32. (a)	33. (d)	34. (d)	35. (b)	36. (a)	37. (a)	38. (c)	39. (b)	40. (a)
41. (d)	42. (c)	43. (c)	44. (a)	45. (a)	46. (c)	47. (a)	48. (b)	49. (c)	50. (a)
51. (d)	52. (a)	53. (b)	54. (c)	55. (a)	56. (c)	57. (b)	58. (d)	59. (c)	60. (a)
61. (a)	62. (d)	63. (d)	64. (b)	65. (b)	66. (c)	67. (c)	68. (a)	69. (c)	70. (d)
71. (a)	72. (c)	73. (d)	74. (c)	75. (a)	76. (b)	77. (c)	78. (b)	79. (d)	80. (b)
81. (d)	82. (b)	83. (d)	84. (b)	85. (b)	86. (c)	87. (b)	88. (b)	89. (b)	90. (c)
91. (d)	92. (d)	93. (d)	94. (b)	95. (c)	96. (b)	97. (d)	98. (a)	99. (c)	100. (b)
101. (c)	102. (a)	103. (a)	104. (c)	105. (b)	106. (a)	107. (b)	108. (d)	109. (d)	110. (d)
111. (c)	112. (c)	113. (c)	114. (c)	115. (b)	116. (a)	117. (c)			

DIGITAL ELECTRONIC CIRCUITS

8.1 BOOLEAN ALGEBRA

George Boolean developed rules for manipulation of binary variable, known as Boolean algebra.

Table for Boolean

1.	$0.A = 0$	$A + 0 = A$
2.	$A.1 = A$	$A + 1 = 1$
3.	$A.A = A$	$A + A = A$
4.	$A.A' = 0$	$A + A' = 1$

Duality is defined for hunting tone system just as it is for other axiomatic system and the dual of a given expression can be derive for simply replacing the “.” with “+” and “+” with “.” and 0’s with 1’s and 1’s with 0’s in the expression.

Algebraic Theorems

- $A + AB = A$
- $A + \overline{A}B = A + B$
- $AB + \overline{A}B = B$
- $AC + \overline{A}BC = AC + BC$
- $AB + AC + \overline{B}C = AB + \overline{B}C$
- $\overline{A.B.C} = \overline{A} + \overline{B} + \overline{C}$
- $\overline{A + B + C} = \overline{A}. \overline{B}. \overline{C}$

8.2 MINIMIZATION OF BOOLEAN FUNCTIONS

Boolean function is an expression formed with binary variable, two binary operators AND and OR, unary operator, Parenthesis and equal sign.

Standard Representations for Logical Functions

Any arbitrary logic function can be expressed in the following forms:

- Sum-of-product (SOP), and
- Product-of-sums form (POS)

- A Boolean function expressed as sum of minterms is called as **SOP (Sum of Products)**.
- A Boolean function expressed as the product of maxterms is called a **POS (Product of Sum)**.
- Boolean functions expressed as sum of minterms or product of maxterms are said to be in canonical form.
- Possible functions that can form with “n” variables in 2^{2^n} .
- Complement of a function expressed as the sum of minterms equals to the sum of minterms missing from the original function e.g.,

$$F(A, B, C) = \sum(1, 4, 5, 6, 7)$$

$$= m_1 + m_4 + m_5 + m_6 + m_7$$

$$\overline{F}(A, B, C) = \sum(0, 2, 3)$$

$$= m_0 + m_2 + m_3$$

Applying De Morgan’s law and finding complement of $\overline{F}(A, B, C)$ we get

$$\overline{\overline{F}}(A, B, C) = \overline{(m_0 + m_2 + m_3)}$$

$$= \overline{m_0} \cdot \overline{m_2} \cdot \overline{m_3}$$

$$= M_0 M_2 M_3 = \prod(0, 2, 3)$$

$$F(A, B, C) = \sum(1, 4, 5, 6, 7)$$

$$= \prod(0, 2, 3)$$

Following methods can be used to simplify the Boolean function:

1. Algebraic method
2. K-map technique
3. Variable entered mapping (VEM) technique and
4. Quine-Mc Cluskey method

Do not care conditions:

Sometimes we come across cases in which certain input combinations never occur. For example, in BCD system 1010 to 1111 are never used and are known as do not care terms. We do not care what the function output is to be because they are guaranteed never to occur. These do not care conditions can be used on a map to provide further simplification of the function. To distinguish the do not care from 1's and 0's an X will be used to represent.

8.3 LOGIC GATES

- Universal gates are those which can be used to get desired basic operation i.e., AND, OR, NOT, operations.

Logic Gates

The boolean operators

AND, OR, NOT and others are represented by logic gates

AND



Fig. 8.1

OR

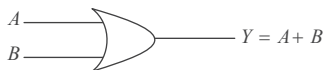


Fig. 8.2

NOT

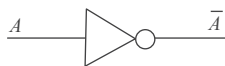


Fig. 8.3

NAND

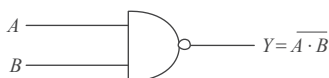


Fig. 8.4

NOR

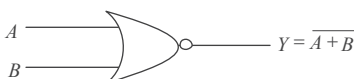


Fig. 8.5

EX-OR

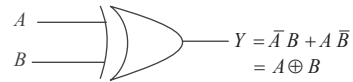


Fig. 8.6

EX-NOR

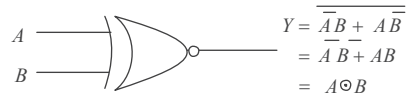


Fig. 8.7

Phantom or Wired logic

Some NAND or NOR gates allow the possibility of a wire connection between the outputs of two gates to provide a specific logic function. This type of logic is called wired logic.

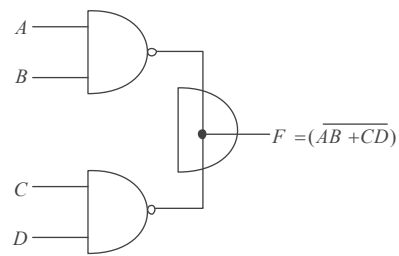


Fig. 8.8

Wired AND (AND-OR Invert)

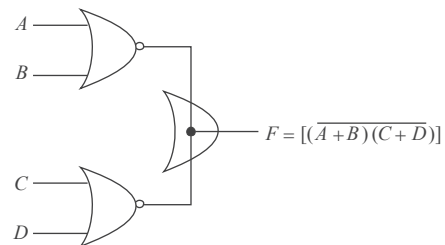
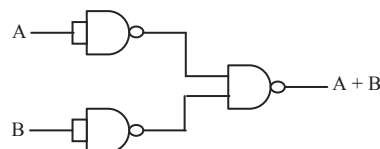


Fig. 8.9

Wired OR (OR-AND Invert)

OR using NAND



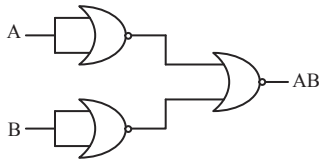
NOT using NAND



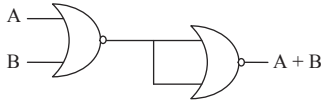
Fig. 8.10

NOR = gate also used to find operation similar to that of AND, OR and NOT.

1. AND using NOR



2. OR using NOR



3. NOT using NOR

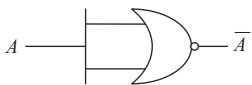


Fig. 8.11

8.4 DIGITAL IC FAMILIES

Digital Signals Voltage Levels

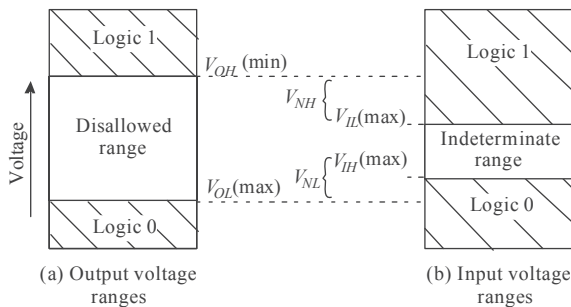


Fig. 8.12 Dc noise margins

Noise margin may be high state noise margin or low state noise margin.

High state noise margin (NM_H) is,

$$V_{NH} = V_{OH(min)} - V_{IH(min)}$$

Low state noise margin (NM_L) is,

$$V_{NL} = V_{IL(max)} - V_{OL(max)}$$

where, V_{OH} = Output voltage at high signal
 V_{OL} = Output voltage at low signal
 V_{IH} = Input voltage at high signal
 V_{IL} = Input voltage at low signal.

- If input voltage to any logic gate is less than V_{IH} , then input may be considered as low (i.e., = 0).
- If input voltage to any logic gate is greater than V_{IH} , then input may be considered as high (i.e., = 1).
- If output voltage of any logic gate is greater than V_{OH} , then output may be considered as high (i.e., = 1).
- Large noise margin better logic gate i.e., less effect of noise. Figure of Merit (FOM) = $T_D \times P_{DP}$
 Where, P_{DP} = Power dissipation
 T_D = delay

Bipolar Logic Families

- Main elements of a bipolar IC (integrated circuit) are resistors, diodes (which are also called capacitors) and transistors.
- Two types of operations in Bipolar IC's:
 1. Saturated
 2. Non-Saturated.

1. In *saturated logic* the transistors in the IC are driven to saturation, so its operation is slow due to charge storage problem.
2. In *Non saturated* case the transistors are not driven into saturation, so its operation is fast.

The Saturated Bipolar Logic Families are

1. (RTL)
2. (DCTL)
3. (I^2L)
4. (DTL)
5. (HTL)
6. (TTL).

The Non-Saturated Bipolar Logic Families

1. Schottky TTL
2. ECL

Unipolar Logic Families

MOS devices are unipolar devices and only enhancement MOSFET'S are employed in MOS logic circuit.

1. PMOS
2. NMOS and
3. CMOS (complementary MOS)

Speed of Operation

The speed of a digital circuit is specified in terms of the propagation delay times. The input and output waveforms of a logic gate are shown below:

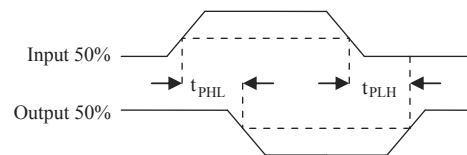


Fig. 8.13

The delay times are measured between the 50% voltage levels of input waveform and output waveform.

Propagation Delays

Delays are associated with the turning-on and the turning-off of the output transistor. While turning on, any capacitance shunting the output of the gate discharges rapidly through the low impedance of the output transistor in saturation. On the other hand, at turn-off, the shunt capacitor must charge through the pull-up resistor R_c in addition to the storage time delay. The turn-off delay is larger than the turn-on delay.

The propagation delay time of commercially available DTL gates are of the order of 30 to 80 n seconds.

There are two Delay Times

t_{PHL} : when the output goes from high to low state.

t_{PLH} : when the out put wave form goes low to high.

The propagation delay time of the logic gate is taken as the average of these two delay times.

$$t_{pd} = \frac{t_{PHL} + t_{PLH}}{2}$$

Power Dissipation

This is the amount of power dissipated in an IC. It is determined by the current I_{cc} , that it draws from the Vcc Supply.

The power dissipation of a gate is given by

$$P_D = V_{CC} \times \frac{I_{CC}(avg)}{n}$$

Where, V_{CC} is the gate supply voltage, $I_{CC}(avg)$ is the average current drawn from the supply by the entire IC and n is the number of gates in the IC. Now

$$V_{CC}(avg) = \frac{I_{CCH} + I_{CCL}}{2}$$

Where, I_{CCH} is the current drawn by the IC when all the gates in the IC are in HIGH state, and

I_{CCL} is the current drawn by the IC when all the gates in the IC are in LOW state.

The total power consumed by an IC is equal to the product of the power dissipated by each gate and the number of gates in that IC.

Figure of Merit

The figure of merit of a digital IC is defined as the product of speed and power. A low value of speed-power product is desirable.

Fan Out

This is the number of similar gates which can be driven by gate. High fan out is an advantage because it reduces the need for addition drivers to drive more gates.

$$\text{HIGH state fan out} = \frac{I_{OH(max)}}{I_{IH}}$$

$$\text{LOW state fan out} = \frac{I_{OL(max)}}{I_{IL}}$$

Resistors-Transistor Logic (RTL)

- RTL was the most popular form of logic in common used before the development of IC's.
- RTL circuit consists of resistors and transistors.
- The Basic RTL based NOR gate

Direct-Coupled Transistor Logic (DCTL)

In the RTL, if the base resistors R_B are omitted we obtain DCTL, in which input is directly coupled to bases.

Integrated Injection Logic (I²L)

- It is simple and uses very small silicon area, consumes very little power.
- Easier and cheaper to fabricate, so suitable for MSI and LSI.
- It uses the concept of merging the components i.e., one semi conductor region is part of two or more device, so it is also called as (*MTL merged transistor logic*).

Diode-Transistor Logic (DTL)

- DTL makes use of diode AND or OR gate and transistor inverter in series for making it to be used as NAND and NOR operation.
- DTL is some what more complexed than RTL, but due to **high fan out** and **improved noise margin**, it has replaced RTL. It is slower speed, poor noise margin.

High-Threshold Logic (HTL)

Due to the presence of Electric motors, on-off control circuit, high voltage switching the noise level is quite high and the logic family discussed so far, do not perform the intended function.

For this purpose, DTL gates has been redesigned with a higher supply voltage (15 V).

Diode have been replaced by a zener diode with $V_z = 6.9$ V and resistances have been increased so that Approximately the same current are obtained as in DTL.

- The propagation delay time is adversely affected due to large resistance value.
- The noise margin obtained with this circuit is typically 7 V.

Transistor Switching Times

Due to internal capacitive effects, transistors do not switch in zero time. Let us consider a simple inverter circuit in order to calculate the various time delays involved in the circuit. Figure ahead shows an inverter circuit with collector current waveform when time delays are considered.

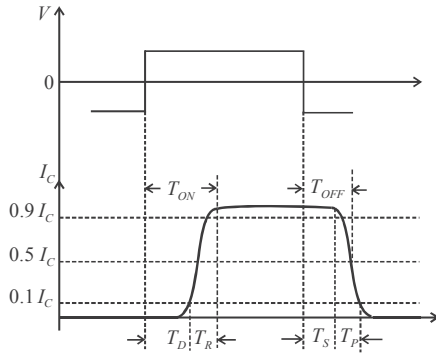


Fig. 8.14

From the waveform above, the different times involved are defined as:

Rise time: It is the time when output is increased from $0.11 I_C$ to $0.91 I_C$. It is denoted by T_R .

$$T_R = h_{fe} \left(C_C R_C + \frac{1}{\omega_T} \right)$$

Where, C_C = collector transistor capacitor

ω_T = frequency at which short circuit current gain becomes unity

Fall Time: When output is decreased from $0.91 I_C$ to $0.11 I_C$. It is denoted by T_F .

Delay time: It is the time required for the output to increase from 0 to $0.11 I_C$. It is denoted by T_D .

It is due to the three factors:

- First factor is the emitter junction transition capacitance. When input is applied to the transistor, it moves from cut-off to active region with changing of transition capacitance.
- When transistor has been brought to the point where minority carrier began to cross the emitter junction into base, a time interval is required before these minority carriers can cross the base region to collector junction.
- Finally some time is required for the collector current to rise 10% of its maximum value.

Storage time: It is the time duration between the transition of input waveform 1 to 0 and time when I_C drops down to 90% is known as storage time.

The transistor cannot respond to the input when input in changing form 1 to 0 because of the presence of minority charge carriers in base of the transistor.

If a capacitance is connected across the base resistor than an impulsive current will flow through the capacitor when input is changing form 1 to 0 and approximately zero storage time is obtained

$$T_{ON} = T_D + T_R ; \quad T_{OFF} = T_S + T_F ; \quad T_{OFF} > T_{ON} > T_S$$

Rise time and Fall time:

It is the time required for the current to rise from $0.1 I_C$ to $0.9 I_C$. Its value is:

Transistor Transistor Logic (TTL)

The input diode in DTL are replaced by emitter-based junctions of multiple-emitter transistor, which is easily and economically fabricated IC.

Totem-Pole Transistor

Q_4 is used because they produce low output impedance which act as power driver or power buffer.

Schottky TTL

Speed limitation of TTL is mainly due to the turn-off time delay involved in transistor while making transition from saturation to cut-off (storage time delay). This can be eliminated by replacing the transistors of TTL gate by Schottky transistor.

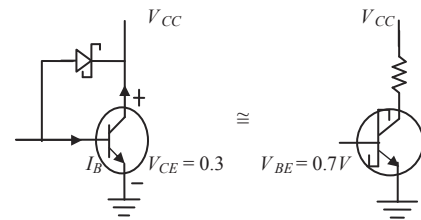


Fig. 8.15

This Schottky transistor prevents transistor from entering saturation and hence, there is saving in turn-off time (Schottky diode is clamped between base and collector).

A Schottky diode works faster as compared to commercial diode because of fact the electron which have crossed the junction and entered the metal, when the current is flowing are similar to the conduction electrons of the metal.

Reverse recovery time for Schottky diode is few p sec rang.

Emitter-Couple Logic (ECL) or Current Mode Logic (CML)

ECL is the fastest of all logic families so used in application where very high speed is essential.

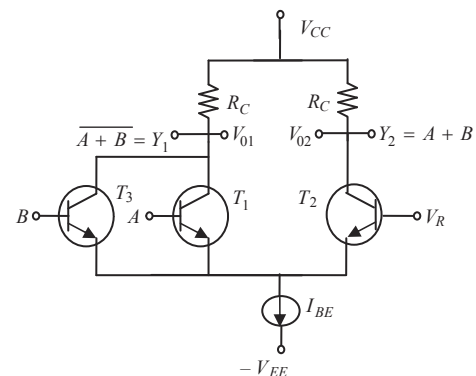


Fig. 8.16

8.6 ■ Digital Electronic Circuits

- High speed is possible in ECL because the transistors are used in difference amplifier either in active or cut-off region and thereby the storage time is eliminated.
- ECL is realized using difference amplifier in which the emitter of the two transistors are connected so called emitter-coupled logic.

MOS-Logic

- High density of fabrication and low power dissipation.
- MOS devices used in logic circuits, are only p or n-channel.
- CMOS lowest power dissipation.

CMOS Based Inverter

This is basic building Block for CMOS circuit:

Circuit diagram

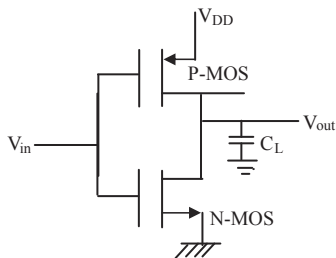


Fig. 8.17

- *Dynamic Power dissipation* is given by

$$P_d = (1/2) C_L V_{DD}^2 f$$
 where, P_d = Dynamic power Dissipation
 V_{DD} = Supply voltage
 f = Switching frequency
 C_L = Load Capacitor.

Logic Families Comparison

Logic	RTL	DTL	HTL	TTL	ECL	MOS	CMOS
Gate	N1	N2	N2	N2	N1/N2	N2	N1/N2
Fan-out	5	8	10	10	25	20	50
Power loss mW	12	8	50	12	40	0.2	0.01
Noise	N	G	E	VG	G	N	VG
Propa gation n sec	12	30	90	12	4	300	70

- * N → Normal,
- * G → Good
- * E → Excellent
- * N2 → NAND
- * S → Satisfactory,
- * VG → Very good
- * N1 → NOR
- * N3 → OR.

8.5 COMBINATIONAL CIRCUIT

A combinational circuits consist of logic gates whose output at any time depends directly from present combination of inputs without regards to previous inputs. No memory in these circuits.

The design requirement of combinational circuit

- A set of statements
- Boolean expression
- Truth table.

8.6 ARITHMETIC CIRCUIT

Most common operation involved in digital system is the arithmetic operation on the binary bits or words.

Adders

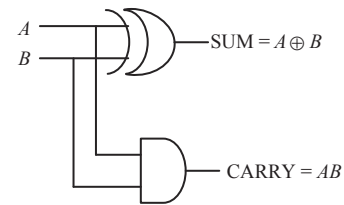
Among the arithmetic operation, addition is the most common. A circuit implementing addition of two bits is called half adders circuit and implementing of three bits is called a full adder.

Half Adder

A logic circuit for the addition of two one-bit number is referred to as an half-adder.

$$S = A \oplus B$$

$$C = AB$$



Realization of an half-adder.

Fig. 8.18

Full Adder

A half adder has only two inputs and there is no provision to add a carry coming from the lower order bits when multibit addition is performed. For this purpose an extra (third) input is added and this circuit is used to add A_n , B_n and C_{n-1} .

$$\text{We have, } S_n = A_n \oplus B_n \oplus C_{n-1}$$

$$C_n = A_n B_n + B_n C_{n-1} + A_n C_{n-1}$$

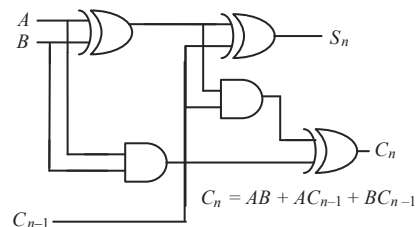


Fig. 8.19

Realization of Full adder using HA and OR gate

Full adder can be realized with two half Adder (HA) and OR gate.

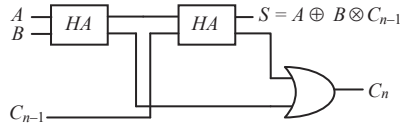


Fig. 8.20

Half Subtractor

(A-B) two bit subtractor

Truth Table

A	B	Difference	Borrow
0	0	0	0
0	1	1	1
1	0	1	0
1	1	0	0

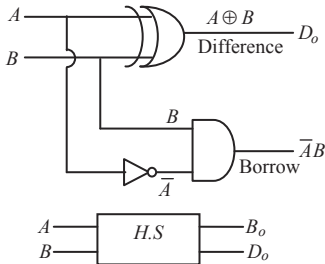
$$A \oplus B = \bar{A}B + \bar{B}A \quad \bar{A}B$$


Fig. 8.21

Comparing with half-adder, borrow is also an AND gate link carry except one input is inverted. So same Half-Adder can be used as half subtractor for one bit with an inverter at one input of AND gate.

Full Subtractor

Full subtraction is a three bit subtractor. Two of the input bit are the operand bits. Third input bit bin indicates borrow taken for subtraction of previous lower significant bit. Two output d and b refer to difference and output borrows respectively.

Truth table for full subtractor

A	B	B _{in}	D	B _{out}
0	0	0	0	0
0	0	1	1	1
0	1	0	1	1
0	1	1	0	1
1	0	0	1	0
1	0	1	0	0
1	1	0	0	0
1	1	1	1	1

$$D = \bar{A} \bar{B} B_{in} + \bar{A} B \bar{B}_{in} + A \bar{B} \bar{B}_{in} + A B B_{in}$$

$$B_{out} = \bar{A} B + \bar{A} \bar{B}_{in} + B B_{in}$$

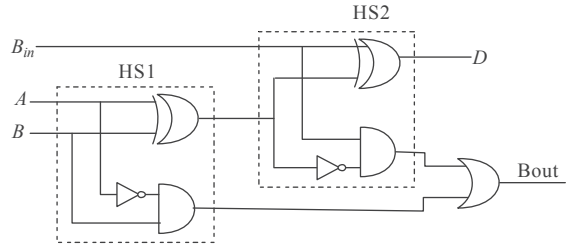


Fig. 8.22

Multiplication and Division

Multiplication is repeated addition and division is repeated subtraction. However multiplier is implemented using multiply, shift and add method. Using accumulator and multiplier registers.

Look Ahead Carry Adder

Consider the following full adder circuit, we define two new binary variables

$$P_i = A_i \oplus B_i$$

$$G_i = A_i B_i$$

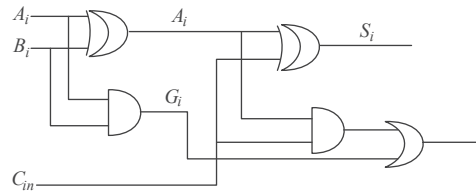


Fig. 8.23

$$S_i = P_i \oplus C_i$$

$$C_{i+1} = G_i + P_i C_i$$

G_i is called carry generate and produces output '1' when A_i and B_i are both '1'. P_i is called carry propagate. Carry for higher significant bits need not have to wait for carry generated in lower significant position. Hence delay due to carry propagation is reduced.

$$C_2 = G_1 + P_1 C_1$$

$$C_3 = G_2 + P_2 C_2 = G_2 + P_2 C_1 + P_2 P_1 C_1$$

$$C_4 = G_3 + P_3 G_2 + P_3 P_2 G_1 + P_3 P_2 P_1 C_1$$

BCD adder

A BCD adder adds two BCD digitals in parallel and produces an BCD sum output. BCD adder must contain the correction logic. When output carry of four bit adder is zero nothing is added to binary sum. When it is equal to one binary 0110 is added to binary sum.

Comparator

Magnitude comparator is a combination circuit that compares magnitude. The output is indicated by three binary variable that indicates whether $A > B$, $A = B$ or $A < B$.

One Bit Comparator

Suppose you have two, one bit number A and B .

$A > B$ only if $A = 1$ and $B = 0$ i.e., $C = A\bar{B} = 1$

$A < B$ only if $A = 0$ and $B = 1$ i.e., $D = \bar{A}B = 1$

$A = B$ if ($A = 1$ and $B = 1$) or ($A = 0$ and $B = 0$)

So,

$A > B$ should give high signal when $A\bar{B}$ is high

$A < B$ should give high signal when $\bar{A}B$ is high

$A = B$ should give high signal when $\overline{AB + \bar{A}\bar{B}}$ is high.

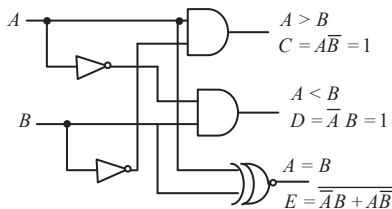


Fig. 8.24

8.7 CODE AND CODE CONVERTER

Codes

It is a symbolic representation of information transform. Generally, four bit codes are used.

Binary Code

If X = Number of element of information to code into binary coded format.

J = Number of bits in a code, then following expression must hold

$$X \leq 2^J; \quad J \geq \log 2^X$$

$$J \geq 3.32 \log_{10} X.$$

Weighted Codes

Starting at the MSB, the places of the code are weighted in decreasing powers of 2. Such a code is also called as 8, 4, 2, 1 weight codes. These codes are useful because of the compact way then can be described.

$$1001 = 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 = 9_{10}$$

Where,

$$N = \sum_{i=0}^{n-1} a_i w_i + B$$

$a_i \rightarrow$ code coefficient

$w_i \rightarrow$ weight

$B \rightarrow$ positive or negative bias

$n \rightarrow$ Bits in the code

Self-Complementary Codes

Certain codes have a distinct advantage in that their logical complement is same as the arithmetic complement.

Examples are Excess-3, 6311, 2421 codes.

Reflective Codes

The 9's complement of reflected BCD code word is simply by changing only one fits bits. A reflected code is characterized by the fact that it is immerged about the center entries with one bit changed.

Unit Distance Code

One bit change in the next or adjacent code word. Independent of the direction has taken in the code.

The unit distance codes have a special advantage in that they minimize transition error or flashing.

Excess-3 Code

This is also known as self-complementing code. Each decimal digit is coded into a 4-digit binary code. The code for each decimal digit is obtained by adding decimal 3 to the natural BCD.

1. It is unweighted code.
2. It is self complementary code.

Gray Code

In this code, a decimal number is represented in binary from is such a way of that each gray-code number differs from the preceding and the succeeding number by a single bit.

1. It has reflection properties
2. Unweighted code
3. Unit distance code
4. More error free code, used for input/output devices.

Error Detecting and Correcting Codes

When the digital information in the binary form is transmitted from one circuit or system to another circuit, an error may occur. This means a signal corresponding to '0' may change to '1' and vice versa.

A simple process of improving data integrity in digital system is obtained by adding one additional bit in the data known as **parity bit**.

This extra bit allows the detection of a single error in transmission.

Error detecting code

Two methods of error detection are:

- Odd parity check
- Even parity check.

Even parity: It means the number of 1's in a digital data is even.

Odd parity: It means the number of 1's in a digital data is odd.

Error Correcting Code

These codes are capable of detecting and correcting errors. These are for a single bit error detector.

Block Parity Codes

If there is N-rows and M-columns of message bits, an odd parity is added to each row and an even parity is added to each column. A final check is carried out at the intersection of the column and row. This will show the location of the faulty bit such as a bit in the 3rd column and 4th row, p_{ij} .

Binary-to-Gray Code Converter

Suppose B_0, B_1, B_2, B_3 (are four bit) input in Binary form and G_0, G_1, G_2, G_3 (output in Gray Code).

So we have,

$$G_3 = B_3$$

$$G_2 = B_2 \oplus B_3$$

$$G_1 = B_1 \oplus B_2$$

$$G_0 = B_0 \oplus B_1$$

8.8 MULTIPLEXER

The multiplexer is a *special combinational circuit* that is used most widely. It is a logic circuit that gates one out of several inputs to a single output. The input selected is controlled by a set of selected inputs. A multiplexer selects one out of N data inputs and feed it into the single line. It is equivalent to single pole multi position switch. The selection of the input lines is controlled by a set of selection line. Hence, MUX is called the data selector.

Input MUX

Basically a MUX consists of an AND and OR gate circuits with an inverter in the select line. There is one AND gate for each input.

$D_0, D_1, D_2 \Rightarrow$ refer to input data

$S_0, S_1, S_2 \Rightarrow$ refer to Control data

$Y_0, Y_1, T_2 \Rightarrow$ refer to output data

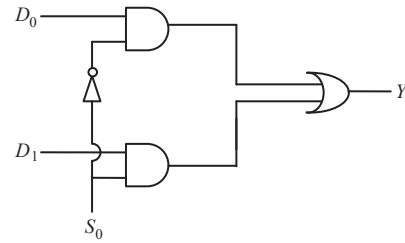


Fig. 8.25

The Boolean functions is $Y = D_0 \bar{S}_0 + D_1 S_0$

Truth Table

S_0	Y
0	D_0
1	D_1

We see from the truth table that so controls or selects the output y .

If $S_0 = 0$, $Y = D_0$

If $S_0 = 1$, $Y = D_1$

An AND-OR gate is equivalent to NAND-NAND gate and hence we can drive any logic function.

Number of select line = $\log_2 n$

where, n = number of input/output for MUX/ DEMUX.

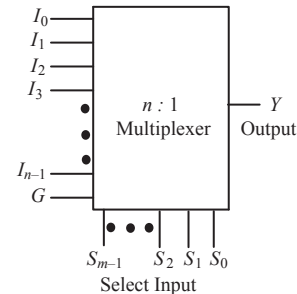


Fig. 8.26

Truth table of a 4:1 multiplexer

Select	Input	Output
S_1	S_2	(Y)
0	0	I_0
0	1	I_1
1	0	I_2
1	1	I_3

$$y = \bar{S}_1 \bar{S}_0 I_0 + \bar{S}_1 S_0 I_1 + S_1 \bar{S}_0 I_2 + S_1 S_0 I_3.$$

Use of MUX

- 1. Data selection
- 2. Time division multiplexing (TDM)
- 3. Function generation
- 4. Universal logic circuit-SOP.

Comparison of Multiplexer and Decoder

- Only one decoder is necessary to generate all minterms. However, the number of OR gates required is equal to the number of outputs.
- One multiplexer is required for each output function.
- So, if the outputs are small in number, multiplexers are used. Decoder IC's are used for large output function.

Encoder

Encoder is a combinational circuit that performs the reverse operation from that of a decoder. It generates a binary code for its 2^n input lines.

8.9 SEQUENTIAL CIRCUIT

Consists of combinational circuit, which accept digital signals from external inputs and output of memory elements.

Two categories:

- 1. Asynchronous
- 2. Synchronous.

A 1-Bit Memory Cell

The basic digital memory circuit is known as *flip-flop*. It has two stable, 1 state and 0 state.

It consists of two inverters G_1 and G_2 (NAND gates based).

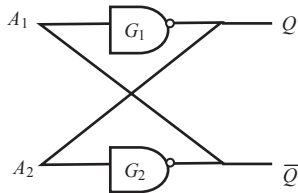


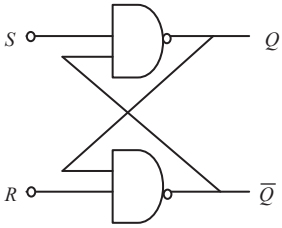
Fig. 8.27

- The output Q and $\bar{Q}$ are complementary.
- The circuits has two states, in one of the stable state $Q = 1$ which is known as (set state), where as in the other hand, other stable $Q = 0$ known as (reset state).
- If the circuit is in state 1, it continues to remain in this state and similarly if it is in 0 state. This property is known as memory, it can store 1-bit of digital information.
- This circuit is also known as **latch**.

Latches

The storage devices called latches form one class of Flip-Flop. This class is characterized by the fact that the timing of the output charge is not controlled. That is output essentially responds immediately to charger on the input line. There are asynchronous in nature.

S-R Latch



S_n	R_n	Q_n	Q_{n+1}
0	0	Not allowed	
0	1	X	1
1	0	X	0
1	1	Q_n	Q_n

Fig. 8.28 State Table

Flip-Flop

A Flip-Flop circuit can maintain a binary state indefinitely until directed by an input signal to switch states. By adding gates to the inputs of the Flip-Flop, the Flip-Flop can be made to respond to input levels during the occurrence of clock.

Clocked S-R flip-flop

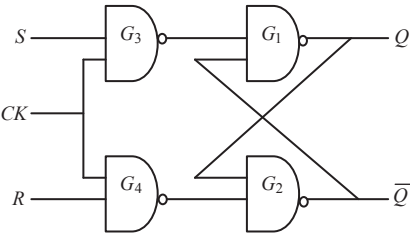


Fig. 8.29

Truth Table of S-R Flip-Flop

Inputs		Output
S_n	R_n	Q_{n+1}
0	0	Q_n
1	0	1
0	1	0
1	1	NA/Prohibit

State Table

Q_n	S_n	R_n	Q_{n+1}
0	0	0	0
	0	1	0
	1	0	1←
	1	1	?
1	0	0	1←
	0	1	0
	1	0	1←
	1	1	?

$$Q_{n+1} = \bar{Q}_n S_n \bar{R}_n + Q_n \bar{S}_n \bar{R}_n + Q_n S_n \bar{R}_n$$

K-map for SR F.F

	$\overline{S}_n \overline{R}_n$	$S_n \overline{R}_n$	$S_n R_n$	$\overline{S}_n R_n$
Q_n		1		
$\overline{Q}_n$	1			

$$Q_{n+1} = S_n \overline{R}_n + \overline{R}_n Q_n.$$

Excitation table for S-R

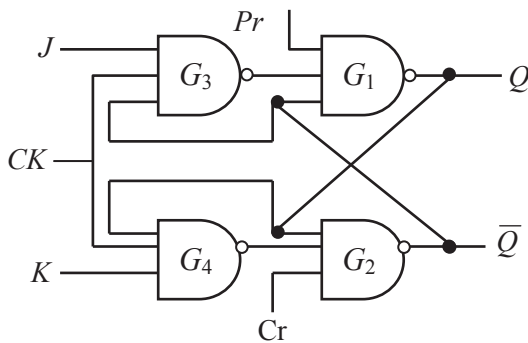
Q_n	Q_{n+1}	S_n	R_n
0	0	0	ϕ
0	1	1	0
1	0	0	1
1	1	ϕ	0

where, ϕ = (don't care).

J-K Flip-Flop

The difficulty of both inputs 1 ($S = R = 1$) being not allowed in an S-R flip-flop is eliminated in J-K flip-flop by using the feedback connection from outputs to the input of the gates. When $J = K = 1$ and $Q_{n+1} = \overline{Q}_n$ i.e., toggle state occurs.

J-K FF is called a **universal flip-flop** because the other FF_s like D, S-R, T can be derived from it. It is a versatile device.

**Fig. 8.30****JK Flip Flop Using NAND Gates**

Pr = Present and

Cr = clear (are asynchronous input).

Truth Table for JK

Inputs		Output
J_n	K_n	Q_{n+1}
0	0	Q_n
0	1	0
1	0	1
1	1	$\overline{Q}_n$

State Table for JK

Q_n	J_n	K_n	Q_{n+1}
0	0	0	0
	0	1	0
	1	0	1←
	1	1	1←
1	0	0	1←
	0	1	0
	1	0	1←
	1	1	0

$$Q_{n+1} = \overline{Q}_n J_n \overline{K}_n + \overline{Q}_n J_n K_n + Q_n \overline{J}_n \overline{K}_n + Q_n J_n \overline{K}_n$$

K-map for JK

	$J_n \overline{K}_n$	$J_n K_n$	$\overline{J}_n \overline{K}_n$	$\overline{J}_n K_n$
Q_n		1		
$\overline{Q}_n$	1			

$$Q_{n+1} = J_n \overline{Q}_n + \overline{K}_n Q_n.$$

Excitation Table for JK

Q_n	Q_{n+1}	J_n	K_n
0	0	0	ϕ
0	1	1	ϕ
1	0	ϕ	1
1	1	ϕ	0

The Race-Around Condition

Because of the feedback connection in JK Flip-Flop a C signal which remains high (=1) while ($J=K=1$) after the output have been complemented one will cause continuous transition of the output. To avoid this undesirable operation the clock pulsed must have a time duration which is shorter than the propagation delay of Flip-Flop. The above mentioned condition occurring in a JK Flip-Flop is called race-around condition and instead of using smaller pulse widths two other configurations are used: Master slave configuration and edge triggered configuration.

Triggering of Flip Flop

There are two modes of triggering of FF's:

1. Level Triggering
2. Edge Triggering

The Master-Slave J-K flip-flop

A master-slave J-K flip-flop is a cascade of two S-R flip-flops, with feedback from the output of the second to the inputs of the first.

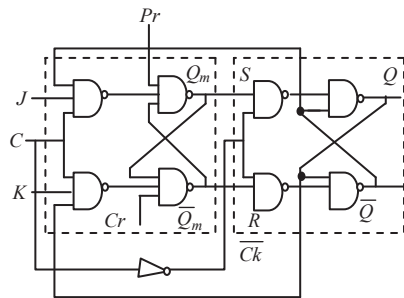


Fig. 8.31

T-FF

T-stand for Toggle

It is derived from J-K flip-flop by joining J and K input.

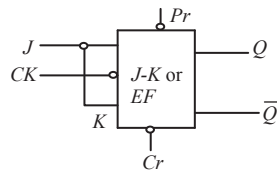


Fig. 8.32

Truth Table

T_n	Q_{n+1}
0	Q_n
1	$\bar{Q}_n$

State Table

Q_n	T_n	Q_{n+1}
0	0	0
	1	1←
1	0	1←
	1	0

$$Q_{n+1} = T_n \bar{Q}_n + \bar{T}_n Q_n = Q_n \oplus T_n.$$

Excitation Table For T FF

Q_n	Q_{n+1}	T_n
0	0	0
0	1	1
1	0	1
1	1	0

D-FF

D-Stands for Delay.

It is derived from J-K flip-flop by giving D input to J and inverted input to K.

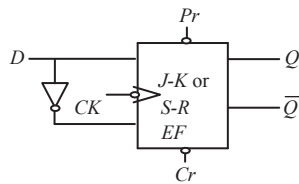


Fig. 8.33

Truth Table for D-FF

D_n	Q_{n+1}
0	0
1	1

State Table

Q_n	D_n	Q_{n+1}
0	0	0
	1	1←
1	0	0
	1	1←

$$Q_{n+1} = D_n$$

Excitation Table for DFF

Q_n	Q_{n+1}	D_n
0	0	0
0	1	1
1	0	0
1	1	1

Conversion of Flip-Flops

Conversion of one FF to another is done by preceding the given FF be a combinational logic circuit in following steps:

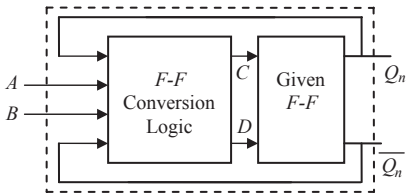


Fig. 8.34

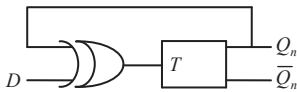
1. Write excitation table for available/given FF and FF to which it is to be converted.
2. Find expression for input C and D of FF in term of output Q_n and input of the target FF.
3. Draw the logic circuit based on expression.

Converting T to D flip flop

Q_n	Q_{n+1}	T_n	D_n
0	0	0	0
0	1	1←	1
1	0	1←	0
1	1	0	1

Expression for T in term of D and Q_n , we get

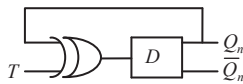
$$T = \bar{Q}_n D + Q_n \bar{D} = D \oplus Q_n$$

**Fig. 8.35****Converting D to T Flip Flop**

Q_n	Q_{n+1}	T_n	D_n
0	0	0	0
0	1	1	1←
1	0	1	0
1	1	0	1←

Expression for D in term of T and Q_n , we get

$$D = \bar{Q}_n T + Q_n \bar{T} = T \oplus Q_n$$

**Fig. 8.36****Flip-Flop timing Considerations**

For edge triggered FF's two timing considerations should be met in order to have reliable FF operation.

Setup time T_s : Time interval immediately preceding the active transition of the CLK signal during which the control input must be maintained at a proper level.

Hold time T_h : Time interval immediately following the active transition of the clock signal during which the control input must be maintained at a proper level.

Maximum frequency: This is the highest frequency of the clock pulse that is to be applied to CLK of FF.

$$f_{\max} < \frac{1}{t_s + t_{pd} + t_{ns}}$$

Where,

t_s = Setup time

t_{pd} = Propagation delay f FF]

t_{ns} = Propagation delay of net stage.

Uses of FFs

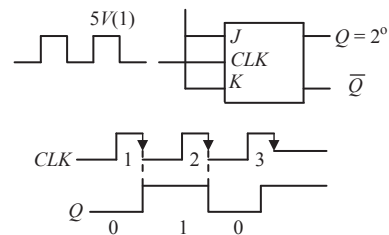
- Wide and extensive application in semiconductor memories counters, shift and storage registers.
- Used for binary addition, serial decoder, comparison and timing function.

8.10 COUNTERS

Counter are cascaded arrangement of flip-flops generating a defined binary sequence.

Counters are used for measurement of frequency and its inverse, time period, sequencing of equipment operation, frequency division, and mathematical manipulation.

A clocked J-K flip-flop function as a counter. A J-K flip-flop functions as a T-FF with both input J and K tied and kept HIGH(1) and when negative edge triggered toggles to the opposite state $Q_{n+1} = \bar{Q}_n$

**Fig. 8.37**

A single FF (J-K used as T) function as a divide by 2^N counter of N FF, it will be divided by N counter where, N is a power of 2

$$\text{MOD of a counter } n = 2^N$$

$$N \rightarrow \text{No. of FFs}$$

Hint: If there are 4 FFs, the modulus $n = 16$, this means a counter with 4 FFs can read a maximum decimal number that N FFs can read is $2^N - 1$.

Two Type of Counters

1. Binary counter
2. Non-binary counter.

If the maximum binary number is equal to 2^N , it is binary counter; otherwise it is a non-binary counter.

8.14 ■ Digital Electronic Circuits

MOD-16 is a binary counter, whereas MOD10 is not.

Both binary and non-binary counters are classified as synchronous and asynchronous counter.

Asynchronous

If the FFs are connected serially and the output of preceding FF clocks the succeeding FF, it is asynchronous counter as the change of states occurs one after the other. It also known as **ripple counter**.

- For a n-stage counter, the maximum binary count is $2^n - 1$. The counter counts from 0 to $2^n - 1$ (assuming all FF's are reset initially). The output waveform of the last state has a frequency.

$$f = \frac{f_{CLK}}{2^n}$$

This counter can also be used as a frequency divider.

In a **synchronous counter**, all flip-flops are clocked simultaneously with the clock input connected in parallel to the clock pulse.

In case of asynchronous counter clock pulse period should be greater than Nt_{pd} . If in addition there is an interval T_s for strobing i.e., set up time. As number of mode times clock frequency required for making the counter reset i.e., 00.

$$\text{Clock period } T \geq Nt_{pd} + T_s$$

Maximum clock frequency is

$$f \leq \frac{1}{T} \leq \frac{1}{Nt_{pd} + T_s}$$

where, N: no of flip flops

t_{pd} : Propagation delay of one FF.

t_s : Strobing interval.

Glitch

It is an unwanted spike. In the decade counter after decimal 9 or binary 1001 the counter does not recycle to 0000 immediately because of t_{pd} of NAND gate. It is unwanted spike for small duration known as *Glitch*.

Sample and hold circuits

In practice, the sampling of an analog signal is performed by a simple-and-hold circuit. The sampled signal is then quantized and converted to digital form. Usually, the S/H is integrated into the A/D converter.

The S/H is a digitally controlled analog circuit that tracks the analog input signal during the sample mode, and then holds it fixed during the hold mode to the instantaneous values of the signal the time the system is switched from the instantaneous value of the signal at the time the system is switched from the sample mode to the hold mode. Figure 8.38 shows the time-domain response of an ideal S/H circuit.

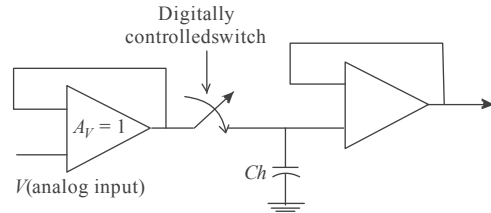


Fig. 8.38

A sample hold converter contains a unity gain buffer amplitude A1.

8.11 A/D AND D/A CONVERTERS

Digital-to-Analog Converters

The input to a D/A converter is an N-bit binary signal. The analog output voltage V_0 of an N-bit straight binary D/A converter is related to the digital input by the equation.

$$V_0 = K(2^{N-1} \cdot b_{n-1} + 2^{N-2} \cdot b_{n-2} + \dots)$$

where, K = Proportionality factor.

$b_n = 1$ if the nth bit of the digital input is 1.

$= 0$ if the nth of the digital input is 0.

D/A Performance Characteristics

- FSV (full scale voltage):** It represents maximum output voltage for the DA converter and is obtained when all bits of digital input are 1.

The output for any bit is $e_0 = V_R / 2^n$

where, n = Number of bits.

$$\text{FSV} = V_R [1 - (1/2^n)].$$

- Resolution:** It is change in the output voltage when the digital input is changed by 1 LSB

$$\% \text{ Resolution} = \frac{\text{Step size}}{\text{FSV}} \times 100 = \frac{1}{2^{n-1}} \times 100.$$

- Accuracy:** It is the error between the actual output of DA converter to the expected or theoretical output and expressed as percentage of FSV.

If the converter has an accuracy of $\pm 0.1\%$ for FSV of 10 V, the minimum error for any output voltage is $[(10/100) \times 0.1] = 10 \text{ mV}$. Ideally the accuracy should be $= \pm [1/2] 1 \text{ LSB}$.

- Monotonicity:** It means that the output increase for an increase of input or decreases for decrease of input. The output should not decrease for increase of input.
- Settling Time:** It is the time taken by DA converter to settle within $\pm [1/2] \text{ LSB}$ of its final value after a change in the input occur.

Two Types of Commonly Used D/A Converters

- Weighted-resistor D/A converter and
- R-2R ladder D/A converter.

Weight-Resistor D/A converter

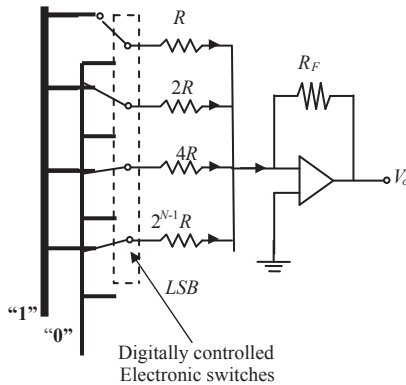


Fig. 8.39

Resistor for MSB = R

Resistor for LSB = $2^{N-1}R$

$$V_o = -V_R \left(\frac{R_F}{R} b_N + \frac{R_F}{2R} b_{N-1} + \dots + \frac{R_F}{2^{N-1}R} b_1 \right)$$

Major components of the binary weighted resistance DAC:

- A weighted resistor network, R to $2^{n-1}R$
- n switches, one for each bit applied bit input.
- A reference voltage V_{ref}
- A summing element.

Defects: The chief defect of weighted binary DAC is that the resistor values increase in multiples of 2.

If the value of MSB is $2\text{ K}\Omega$. then for a 10 bit, the value for LSB is $2^9 \cdot 2\text{ K} = 1.024\text{ M}\Omega$.

It is difficult to obtain high precision at very high values. It is also difficult to fabricate high value resistance by integrated circuit methods. This is overcome by the ladder type DA converter.

R-2R ladder Network

In this, only two values of resistors are used.

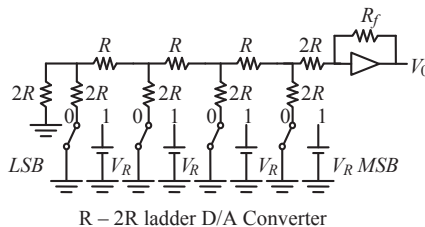


Fig. 8.40

$$V_o = V_R (2^{N-1} b_{N-1} + 2^{N-2} b_{N-2} + \dots + b_0) / 2^N$$

The number of resistors required for an N-bit ladder D/A converter is $2N$ in the case of R-2R ladder D/A converter, whereas, it is only N in the case of weighted-resistor D/A converter.

Analog-to-digital converters: Types of ADC

1. Parallel-comparator/flash/simultaneous A/D

- Simplest in concept and fastest conversion time.
- Disadvantage is rapid increase in the number of comparators with the number of bits, $(2^N - 1)$ comparators are required for an N-bit converter.

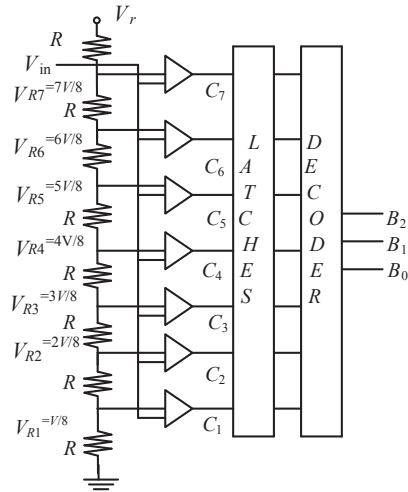


Fig. 8.41

2. Successive Approximation A/D converter.

- For N-bit converter, the number of clock pulses required would be N .
- Slow than the parallel-comparator A/D
Offset voltage = $1/2\text{ LSB} - 0.5$.
- Conversion time independent of input voltage value.

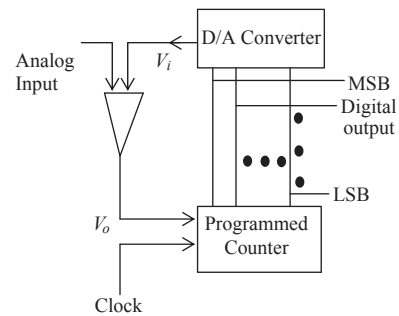


Fig. 8.42

3. Counter or ramp A/D converter

The maximum number of clock pulse required conversion is 2^N for an N-bit A/D converter. This converter is slower than the other two converters discussed earlier.

4. Dual-slope A/D converters

Major components of a dual-slope A/D converter are:

1. An integrator
2. A comparator
3. A binary counter
4. A switch driver.

Conversion time of ADC

1. Counter or Ramp type ADC

$$t_c = \frac{(2^n - 1)}{f} = (2^n - 1)T$$

$$= \frac{V_{in}}{V_{ref}} \times \frac{2^n}{f}$$

2. Successive approximation ADC

$$t_c = \frac{[n]}{f} = nT.$$

3. Dual slope ADC

Slowest conversion time.

4. Flash ADC

Fastest conversion time $t_c = (1/f) = T$

- Conversion time independent from number of bit.
- The number of Comparator = $2^n - 1$
where, f = clock frequency.

Aperture Time

Aperture time is called the maximum allowable conversion time t_a .

$$t_a = \frac{1}{\omega(2^n - 1)}$$

where, ω = angular frequency of signal applied n = number of bit for ADC. t_a = aperture time.**Semiconductor Memories**

There are two types of main memory sometimes called **core memory**, ROM and RAM. **ROM** is Read only Memory. It is a nonvolatile memory and its contents remain permanent even after removal of power. Its contents of binary pattern of 1's and 0's are permanently programmed by the manufacturer.

ROM is basically an encoder with the i th storage location in memory addressed by setting on input $Z_i = 1$

RAM is Random Access Memory but generally called Read/Write Memory (RWM). It is a volatile memory as its contents are erased on removal of power even momentarily. It can be easily programmed, erased and reprogrammed by the user. Placing contents into the memory is called writing and copying data from the memory without destroying is called reading from memory. It is called Random Access because any memory cell can be approached directly without the need to proceed from the first cell onwards sequentially.

EEPROM or E²Prom or EAPROM

Electrically Erasable or Alterable Programmable, ROM, its cells can be programmed erased electrically and reprogrammed many times by using special equipment without removing the IC memory from the sockets. They are manufactured using *Metal Nitride-Oxide Semiconductor (MNOS)* technology or other technology, which uses amorphous semiconductor such as tellurium. E²PROM are generally used

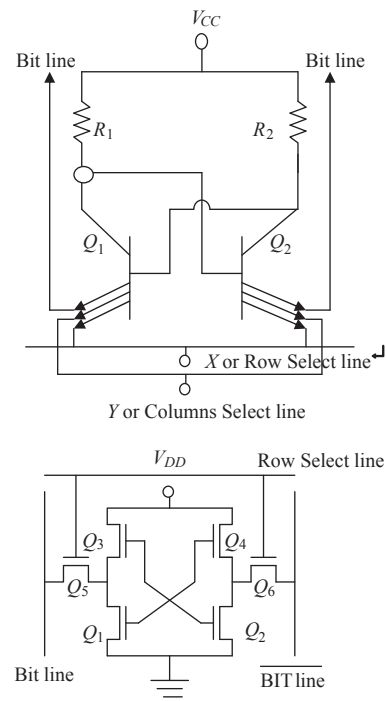
for read operations as its write time is more i.e., slower than read time.

RAM is divided into Static RAM (SRAM), Dynamic RAM (DRAM) and *quasistatic* RAM. SRAM is built of flip-flop circuits using transistors or MOSFETs. MOS circuit is preferred to transistor as it consumes very little power with greater packing density and consequent less cost. However bipolar RAMs have faster access time.

DRAM uses a single MOS with capacitor (stray) which requires to be refreshed frequently at millisecond intervals unlike SRAM which need not be refreshed and holds the data indefinitely until power supply is on. Dynamic RAMs have the advantage of higher capacity and lower power consumption over SRAMs and hence are used in large memory systems. *Quasistatic RAMs have an internal battery for refreshing.*

RAM Circuits**Bipolar RAMs**

A bipolar transistor RAM is a static RAM which retains the data on the bit line indefinitely until switched off. The circuit consists of two multiemitter cross coupled transistors operating as a bistable multivibrator. In a multiemitter operation when one emitter is low (0 V) and the other high (3 V) emitter current flows through the low level emitter as that V_{BE} is positive. A number of these cells are arranged in a rectangular matrix array in rows and columns and a cell located at the junction of row and column. The rows are words and column bits. To read from the cell the row and column select lines are made high (3 to 5 V). If Q_1 is on, current will flow through the bit line and sensed by a difference amplifier as logic 0 Q_2 off will be logic 1.

**Fig. 8.43**

Dynamic MOS RAMs (DRAM)

This consists of a single CMOS and one capacitor which is charged and discharged.

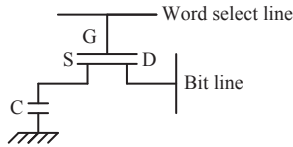


Fig. 8.44

PROM: Programmable ROMs are programmed by the user according to his requirement.

In the circuit, there is a fusible link of titanium tungsten ($0.15\ \mu\text{m}$) used which is broken by a high current pulse (20 mA) for about 20 ms for a 0 and left intact for logic 1. The manufacturer supplies the chip with all cells connected. Once programmed no change is possible. Three types of links are used, metal, silicon and avalanche induced migration. In the third one, diode of a back-to-back connected PN junction is shorted by an avalanche.

EPROM

In this, programme can be erased and reprogrammed. They use NMOS devices with an isolated gate. During programming charge is injected into the insulated gate where it remains for an indefinite time. A bit 0 or 1 is identified by the absence or presence of a charged gate. The charges on the gate are removed by a UV light ($12\ \text{mW}/\text{cm}^2$) through a quartz window which

neutralizes the charge by photo current. Glass is opaque to UV light.

EAPROMs. This is also called as *Read Mostly memory*.

ROM An Their Applications

Look up tables: Such as trigonometric functions, logarithms, exponentials, square roots etc., they are programmed at the factory and called masked ROMs.

There are three different types of PLAs

1. **PROM:** Programmable Read Only Memory which can be programmed at the site. ROM is a matrix of an AND array and an OR array. The PROM consists of fixed AND array and a programmed OR array. If there are three variables A, B, C the AND array will have $2^3 = 8$ minterms from $\bar{A}\bar{B}\bar{C}$ to ABC .
2. **PAL, (Programmable Array logic):** In this, the AND array is programmable and OR array is fixed. Since the AND array is programmable there will be a fusible link at every intersection and there will be only specific OR connections. If there are four variables A, B, C, D and four outputs the AND array will have

$$2^4 = 16 \times 8(A, \bar{A}, B, \bar{B}, C, \bar{C}, D, \bar{D}) = 128$$
 fusible links.
3. **PAL (Programmable Array Logic):** Here both the AND and OR arrays are programmable. There will be a fusible link at each intersection. If there are four inputs A, B, C, D , the AND array will have as before $2^4 = 16 \times 8 = 128$ fusible links. The OR array will have $4 \times 16 = 64$ fusible links.

QUESTION BANK

LEVEL 1

1. Which one of the following statements correctly defines the full-adder?
An adder circuit
 - (a) Having two inputs used to add two binary digits. It produces their sum and carry as input
 - (b) Having three inputs used to add two binary digits plus a carry. It produces their sum and carry as output
 - (c) Used in least significant position when adding two binary digits with no carry-in to consider, it produces their sum and carry as output
 - (d) Having two inputs and two outputs
2. Consider the following statements:
A multiplexer
 1. Selects one of the several inputs and transmit it to a single output
 2. Routes the data from a single input to one of many outputs
 3. Converts parallel data into serial data
 4. Is a combinational circuit
 Which of these statements are correct?
 - (a) 1, 2 and 4
 - (b) 2, 3 and 4
 - (c) 1, 3 and 4
 - (d) 1, 2 and 3
3. Consider the following statements:
 1. Race around condition occurs in a JK flip-flop when the inputs are one
 2. A flip-flop is used to store one bit of information
 3. A transparent latch consists in of D-type flip-flop
 4. Master-slave configuration is used in flip-flop to store two bits of information
 Which of these statements are correct?
 - (a) 1, 2 and 3
 - (b) 1, 3 and 4
 - (c) 1, 2 and 4
 - (d) 2, 3 and 4
4. A crystal oscillator is frequently used in digital circuits for timing purposes because of its
 - (a) Low cost
 - (b) High frequency stability
 - (c) Simple circuitry
 - (d) Ability to set the frequency at the desired value
5. Which one of the following statements is correct?
 - (a) RAM is non-volatile memory whereas ROM is a volatile memory
 - (b) RAM is a volatile memory whereas ROM is non-volatile memory
 - (c) Both RAM and Rom are volatile memories but in ROM data is not lost when power is switched off
 - (d) Both RAM and ROM are non-volatile memories but is RAM data is lost when power is switched off
6. Which of the following regions of operation are mainly responsible for heating of the transistor under switching operation?
 1. Saturation region
 2. Cut-off region
 3. Transition from saturation to cut-off
 4. Transition from cut-off to saturation**Codes:**
 - (a) 1 and 2
 - (b) 2 and 3
 - (c) 3 and 4
 - (d) 1 and 3
7. The decoding error of the counter can be avoided by
 - (a) Increasing propagation delay of flip-flops used in the counter
 - (b) Using very high logic gates
 - (c) Using the strobe signal
 - (d) Reducing the propagation delay of flip-flop used in the counter
8. Which one of the following flags is not used for branching in a microprocessor?
 - (a) Carry flag
 - (b) Auxiliary carry flag
 - (c) Overflow flag
 - (d) Parity flag
9. A relaxation oscillator is one which
 - (a) Has two stable states
 - (b) Oscillates continuously
 - (c) Relaxes indefinitely
 - (d) Produces non-sinusoidal output
10. How is inversion achieved using EX-OR gate?
 - (a) Giving input signal to the two input lines of the gate tied together
 - (b) Giving input to one input line and logic zero to the other line
 - (c) Giving input to one input line and logic one to the other line
 - (d) Inversion can not be achieved using EX-OR gate
11. The code which provides for parity check is
 - (a) Baudot
 - (b) ASCII
 - (c) EBCDIC
 - (d) Excess-3
12. The output of a Moore sequential machine is a function of
 - (a) All present states of the machine
 - (b) All the inputs
 - (c) A few combination of inputs and the present state
 - (d) All the combination of inputs and the present state
13. Consider the following statements:
For a master-slave J-K flip-flop
 1. The toggle frequency is the maximum clock frequency at which the flip-flop will toggle reliably

2. The data input must precede the clock triggering edge transition time by some minimum time
3. The data input must remain fixed for a given time after, the clock triggering edge transition time for reliable operation
4. Propagation delay time is equal to the rise time and fall time of the data

Which of the statements given above are correct?

- (a) 1, 2 and 3 (b) 1, 2 and 4
(c) 1, 3 and 4 (d) 2, 3 and 4

14. Consider the following statements regarding register and latches:

1. Registers are made of edge-triggered FFs, whereas latches are made from level-triggered FFs
2. Registers are temporary storage devices whereas latches are not
3. A latch employs cross-coupled feedback connections
4. A register stores a binary word whereas a latch does not

Which of the statements given above are correct?

- (a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 3 and 4

15. Which one of the following statements describes the operation of a multiplexer?

- (a) A logic circuit used to generate codes output
- (b) A logic circuit used to generate F's complement
- (c) A logic circuit that accepts two or more inputs and allows one of them at a time to get through the output
- (d) A logic circuit that transmits one input to several output lines

16. Which one of the following statements is not correct?

- (a) A full adder can be constructed using two half-adders and an OR gate
- (b) Two four bit parallel adders can be cascaded to construct 8-bit parallel adder
- (c) Ripple carry adder has addition time independent of the number of bits
- (d) Carry look ahead is used to speed up the parallel addition

17. Consider the following statements:

A half-adder

1. Is a half-subtractor also
2. Has two outputs $C_H = x \cdot y$ and $S_H = x \oplus y$ for two inputs x and y
3. Has two outputs $C_H = x + y$ and $S_H = x \oplus y$ for two inputs x and y
4. Is a combinational circuit

Which of the statements given above is/are correct?

- (a) 1, 3 and 4
(b) 1, 2 and 4
(c) 4 only
(d) 2 and 3

18. A Gray code is a/an

- (a) Binary weighted code
- (b) Arithmetic code

- (c) Code which exhibits a single bit change between two successive codes
- (d) Alphanumeric code

19. A Wallace tree is a

- (a) Sequential logic circuit that counts numbers of pulses
- (b) Sequential logic circuit that adds two numbers
- (c) Combinational logic circuit that adds two numbers
- (d) Combinational circuit that multiplies two numbers

20. The Boolean expression $Y(A, B, C) = A + BC$

Is to be realized using two-input gates of only one type. What is the minimum number of gates required for the realization?

- (a) 1 (b) 2
(c) 3 (d) 4 or more

21. Narrow pulses with **adjustable mark to space ratio** can be obtained from square wave input signal by using which of the following?

1. Schmitt trigger
2. Monostable multivibrator
3. Clippers

Select the correct answer using the codes given below:

- (a) Only 1 (b) Only 2
(c) 1 and 2 (d) 2 and 3

22. Which one of the following is correct for ASCII codes of all upper case English letter compared to all lower case English letters?

- (a) Are all larger
- (b) Are all smaller
- (c) Are all equal
- (d) Some are larger and some are smaller

23. A single ROM is used to design a combinational circuit described by a truth-table. What is the number of address lines in the ROM?

- (a) Number of input variables in the truth-table
- (b) Number of output variables in the truth-table
- (c) Number of input plus output variables in the truth-table
- (d) Number of lines in the truth-table

24. Given below are three types of converters:

1. Successive approximation type
2. Weighted resistor type
3. R-2R ladder type

Which of these type are D to A converters?

- (a) Only 1 and 2
(b) Only 2 and 3
(c) Only 1 and 3
(d) 1, 2 and 3

25. Which of the following characteristics are necessary for a sequential circuit?

1. It must have at least six gates
2. It must have some feedback
3. Its output should depend on some past value

Codes:

- (a) 1, 2 and 3 (b) 1 and 3
(c) 2 and 3 (d) 1 and 3
26. A 1 msec pulse can be converted into a 10 msec pulse by using
(a) An astable multivibrator
(b) A monostable multivibrator
(c) A bistable multivibrator
(d) A $J-K$ flip-flop
27. A three-input NAND gate is to be used as an inverter. Which one of the following measures will achieve better result?
(a) The two inputs not used are kept open
(b) The two inputs not used are connected to ground (0 level)
(c) The two inputs not used are connected to logic (1 level)
(d) None of the above
28. Which one of the following statements is correct?
(a) In serial adder, if d and D , respectively, are the full adder and flip-flop delays, then the time required to perform n bit additions is $[n(d + D)]$
(b) Maximum delay in n bit parallel adder is nd , where d is delay of full adder
(c) If d is the delay of two-level circuit, then the total delay of a carry look ahead adder is only $3d$
(d) In serial order, if d and D respectively numbers which can be stored in two's complement form in a 16-bit register are respectively
29. State transition table and state transition diagram form part of the design steps is the case of
(a) combinational circuit
(b) amplifier circuit
(c) delay circuit
(d) sequential circuit
30. Consider the Analog to Digital converter given below:
1. Successive Approximation ADC
2. Dual Ramp ADC
3. Counter method ADC
4. Simultaneous ADC
The correct sequence of the descending order in terms of conversion times of these ADC's is
(a) 3, 2, 4, 1 (b) 2, 3, 4, 1
(c) 2, 3, 1, 4 (d) 3, 2, 1, 4
31. In digital circuit, Schottky transistor preferred over normal transistor because their
(a) Lower propagation delay
(b) Higher propagation delay
(c) Lower power dissipation
(d) Higher power dissipation
32. A full-adder output can be made of
(a) Two half-adders
(b) Two half-adders and a NOT gate
(c) Two half-adders and an OR gate
(d) Two half-adders and an AND gate
33. The voltage levels of a negative logic system
(a) Must necessarily be negative
(b) May be negative or positive
(c) Must necessarily be positive
(d) Must necessarily be 0 V and -5 V
34. $Y = f(A, B) = M(0, 1, 2, 3)$ represents (M is Maxterm)
(a) Nor gate
(b) NAND gate
(c) OR gate
(d) a situation where output is independent of input
35. Consider the following statements regarding IC_s
1. ECL has the least propagation delay
2. TTL has the largest fan-out
3. CMOS has the biggest noise margin
4. TTL has the lowest power consumption
Which of these statements are correct?
(a) 1 and 3
(b) 2 and 4
(c) 3 and 4
(d) 1 and 2
36. For a logic family
 V_{OH} is the minimum output high level voltage
 V_{OL} is the maximum output low level voltage
 V_{IH} is the maximum acceptable input high level voltage
 V_{IL} is the maximum acceptable input low level voltage
The correct relationship among these is
(a) $V_{IH} > V_{OH} > V_{IL} > V_{OL}$
(b) $V_{OH} > V_{IH} > V_{IL} > V_{OL}$
(c) $V_{IH} > V_{OH} > V_{OL} > V_{IL}$
(d) $V_{OH} > V_{IH} > V_{OL} > V_{IL}$
37. The software that transfer the object program from secondary memory to the main memory is called
(a) assembler
(b) loader
(c) linker
(d) task builder
38. Symmetrical square wave of time period 100 μs can be obtained from square wave of time period 10 μs by using a
(a) divide by-5 circuit
(b) divide by-2 circuit
(c) divide by-5 circuit followed by a divide by-2 circuit
(d) BCD counter
39. A 1 μs pulse can be converted into a 1 ms pulses by using
(a) A Monostable multivibrator
(b) An astable multivibrator
(c) A bistable multivibrator
(d) A $J-K$ flip-flop
40. Choose the correct statement(s) from the following:
1. PROM contains a programmable AND array and a fixed OR array

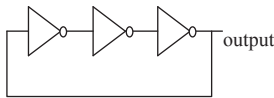
2. PLA contains a fixed AND array and a programmable OR array
 3. PROM contains a fixed AND array and a programmable OR array
 4. PLA contains a programmable AND array and a programmable OR array
- Of these statements:
- (a) only 1 is correct
 - (b) 2 and 3 correct
 - (c) 3 and 4 correct
 - (d) 1 and 4 correct
41. In a microcomputer, the register which holds the address of the next instruction to be fetched is
 - (a) Accumulator
 - (b) Program Counter
 - (c) Stack Pointer
 - (d) Instruction Resistor
 42. Data can be changed from spatial code to temporal code and vice-versa by using
 - (a) ADC_s and DAC_s
 - (b) Shift-registers
 - (c) Synchronous counters
 - (d) Timers
 43. The output of a logic gate is '1' when all its inputs are at logic '0'. Then gate is either
 - (a) A NAND or an EX-OR gate
 - (b) A NOR or an EX-NOR gate
 - (c) An OR or an EX-NOR gate
 - (d) An AND or an EX-OR gate
 44. A PLA can be used
 - (a) As a microprocessor
 - (b) As a dynamic memory
 - (c) To realize a sequential logic
 - (d) To realize a combinational logic
 45. A dynamic RAM consists of
 - (a) 6 transistors
 - (b) 2 transistors and 2 capacitors
 - (c) 1 transistors and 1 capacitors
 - (d) 2 capacitors only
 46. A switch tail ring counter is made by using a single D flip-flop. The resulting circuit is a
 - (a) SR flip-flop
 - (b) JK flip-flop
 - (c) D flip-flop
 - (d) T flip-flop
 47. An R-S latch is a
 - (a) combinational circuit
 - (b) synchronous sequential circuit
 - (c) one bit memory element
 - (d) one clock delay element
 48. Schottky clamping is resorted to in TTL gates
 - (a) To reduce propagation delay
 - (b) To increase noise margins
 - (c) To increase pecking density
 - (d) To increase fan-out
 49. A pulse train can be delayed by a finite number of clock periods using
 - (a) A serial-in serial-out shift register
 - (b) A serial-in parallel-out shift register
 - (c) A parallel-in serial-out shift register
 - (d) A parallel-in parallel-out shift register
 50. In standard TTL, the 'totem pole' stage refers to
 - (a) The multi-emitter input stage
 - (b) The phase splitter
 - (c) The output buffer
 - (d) Open collector output stage
 51. The gate delay of an NMOS inverter is dominated by charge time rather discharge time because
 - (a) The driver transistor has larger threshold voltage than the load transistor
 - (b) The driver transistor has larger leakage current compared to the load transistor
 - (c) The load transistor has smaller W/L ratio compared to the driver transistor
 - (d) Non of the above
 52. The advantage of using a dual slope ADC in a digital voltmeter is that
 - (a) Its conversion time is small
 - (b) Its accuracy is high
 - (c) It gives output in BCD format
 - (d) It does not require a comparator
 53. A Darlington emitter-follower circuit is sometimes used in the output stage of TTL gate in order to
 - (a) Increase its IOL
 - (b) Reduces its I_{OH}
 - (c) Increase its speed of operation
 - (d) Reduce power dissipation
 54. Commercially available ECL gate use two ground lines and one negative supply in order to
 - (a) Reduce power dissipation
 - (b) Increases fan-out
 - (c) Reduces loading effect
 - (d) Eliminate the effect of power line glitches or the biasing circuit
 55. A master-slave flip-flop has the characteristic that
 - (a) Change in the input immediately reflected in the output
 - (b) Change in the output occurs when the state of master is affected
 - (c) Change in the output occurs when the state of the slave is affected
 - (d) Both the master and the slave states are affected at the same time
 56. Dual-slope integration type Analog-to-digital converters provide
 1. Higher speeds compared to all other types of A/D converters

8.22 ■ Digital Electronic Circuits

2. Very good accuracy without putting extreme requirements on component stability
 3. Good rejection of power supply hum
 4. Better resolution compared to all other types of A/D converters for the same number of bits
- Codes:**
- (a) only 1 is correct
 - (b) 2 and 3 correct
 - (c) 1, 2, 3 and 4 correct
 - (d) 2 and 4 correct
57. The desirable characteristics of a digital logic family are
- (1) Large fan-out
 - (2) Large threshold voltage
 - (3) Large noise
 - (4) Margin small threshold voltage
- Choose the correct option
- (a) 1, 2 are correct
 - (b) 2, 3 are correct
 - (c) 1, 3, 4 are correct
 - (d) 1, 3 are correct
58. A sample and hold circuit is normally required before the following type of A/D converter
- (a) Successive approximation
 - (b) Flash (parallel) converter
 - (c) Voltage – to frequency converter
 - (d) Dual slope integrator
59. CMOS logic gate has.
- (a) Highest speed among all logic families
 - (b) Very low quiescent power consumption
 - (c) Very low output impedance
 - (d) None of these
60. The advantage of a dual slope converter over successive approximation converter is that the dual slope converter
- (a) Is faster
 - (b) Eliminates error due to drift
 - (c) Can reduce the errors due to power supply
 - (d) Does not require a stable voltage reference
61. A sample and hold circuit has two buffers, one at the input and the other at the output. The primary requirements for the buffers are
- (a) The input buffer should have high slow rate and the output buffer should have low bias current
 - (b) The input buffer should have low bias current and the output buffer should have high slew rate
 - (c) Both the buffers should have low bias currents
 - (d) Both the buffers should have high slow rate
62. Which one of the following can be used as parallel to series converter?
- (a) Decoder
 - (b) Digital counter
 - (c) Multiplexer
 - (d) Demultiplexer
63. A ring counter consisting of five flip-flop will have
- (a) 5 states
 - (b) 10 states
 - (c) 32 states
 - (d) infinite state
64. Karnaugh map is used to
- (a) Minimize the number of flip-flops in a digital circuit
 - (b) Minimize the number of gates only a digital circuit
 - (c) Minimize the number of gates and fan-in of a digital circuit
 - (d) Design gates
65. CE configuration is the most preferred transistor configuration when used as a switch because it
- (a) Requires only power supply
 - (b) Requires low voltage or current
 - (c) Is easily understood by everyone
 - (d) Has small I_{CEO}
66. Consider the following logic families:
- | | |
|--------|--------|
| 1. MOS | 2. DTL |
| 3. RTL | 4. ECL |
- The sequence of these logic families in the order of their increasing noise margin is
- (a) 3, 4, 1, 2
 - (b) 3, 4, 2, 1
 - (c) 4, 3, 1, 2
 - (d) 4, 3, 2, 1
67. An 8-bit D/A converter has a full scale output voltage of 20 V. The output voltage when the input is 11011011 is
- (a) 160 mV
 - (b) 78 mV
 - (c) 20 V
 - (d) 17 V
68. In the negative logic system
- (a) The more negative of the two logic levels represents a logic '1' state
 - (b) The more negative of the two logic levels represent a logic '0' state
 - (c) All input and output voltage levels are negative
 - (d) The output is always complements of the intended logic function
69. If the output of a logic gate is '1' when all its inputs are at logic '0', the gate is either
- (a) A NAND or a NOR
 - (b) An AND or an EX-NOR
 - (c) An OR or a NAND
 - (d) An EX-OR or an EX-NOR
70. The output voltage of a 5-bit D/A binary ladder that has a digital input of 11010 (assuming 0 = 0 V and 1 = +10 V) is
- (a) 3.4375 V
 - (b) 6.0 V
 - (c) 8.125 V
 - (d) 9.6875 V
71. F'_s complement of (2BFD)_{hex} is
- (a) E 304
 - (b) D 403
 - (c) d 402
 - (d) c 403

LEVEL 2

- Which one of the following is equivalent to the Boolean expression $Y = \bar{A}\bar{B} + \bar{B}\bar{C} + \bar{C}\bar{A}$
 - $\overline{AB + BC + CA}$
 - $(\bar{A} + \bar{B})(\bar{B} + \bar{C})(\bar{A} + \bar{C})$
 - $\overline{(A+B)(B+C)(C+A)}$
 - $(\bar{A} + \bar{B})(\bar{B} + \bar{C})(\bar{C} + \bar{A})$
- Given Boolean theorem $AB + \bar{A}C + BC = AB + \bar{A}C$. Which one of the following identities is true?
 - $(A+B) \cdot (\bar{A}+C) \cdot (B+C) = (A+B) \cdot (\bar{A}+C)$
 - $AB + \bar{A}C + BC = AB + BC$
 - $AB + \bar{A}C + BC = (A+B) \cdot (\bar{A}+C) \cdot (B+C)$
 - $(A+B) \cdot (\bar{A}+C) \cdot (B+C) = AB + \bar{A}C$
- The circuit shown in the given figure



- Is an oscillating circuit and its output is a square wave
 - Is one whose output remains stable in '1' state
 - Is one whose output remains stable in '0' state
 - Gives a single pulse of three times propagation delay
- The number of comparator circuit required to build a three-bit simultaneous A/D converter is
 - 7
 - 8
 - 15
 - 16
 - The number of 4-line-to-16-line decoders required to make an 8-line-to-256-line decoder is
 - 16
 - 17
 - 32
 - 64
 - The characteristic equation of the T-flip-flop is given by
 - $Q^+ = \bar{T}Q + T\bar{Q}$
 - $Q^+ = T\bar{Q} + Q\bar{T}$
 - $Q^+ = TQ$
 - $Q^+ = T\bar{Q}$
 - A relaxation oscillator is one which
 - Has two stable states
 - Oscillates continuously
 - Relaxes indefinitely
 - Produces non-sinusoidal output
 - Four memory chips of 16×4 size have their address buses connected together. This system will be of size
 - 64×4
 - 16×16
 - 32×8
 - 256×1
 - The number of digit 1 present in the binary representation of $3 \times 512 + 7 \times 64 + 5 \times 8 + 3$ is
 - 8
 - 9
 - 10
 - 12

- Consider the Boolean expression

$$X = ABCD + A\bar{B}CD + \bar{A}BCD + \bar{A}\bar{B}CD$$

The simplified form of X is

- $\bar{C} + \bar{D}$
 - BC
 - CD
 - BC
- Which of the following is a self-complementing code?
 - 8421 code
 - Excess 3 code
 - Pure binary code
 - Gray code
 - A **sequence detector** is required to logical output of 1 whenever the sequence 1011 is detected in the incoming pulse stream. Minimum number of flip-flops needed to build the sequence detector is
 - 4
 - 3
 - 2
 - 1
 - A number is expressed in binary two's complement as 10011. Its decimal equivalent value is
 - 19
 - 13
 - 19
 - 13
 - The open collector output of two 2-input NAND gates are connected to a common **pull-up resistor**. If the input of the gates are A, B and C, D respectively, the output is equal to
 - $\overline{AB \cdot CD}$
 - $\overline{A \cdot B + C \cdot D}$
 - $A \cdot B + C \cdot D$
 - $A \cdot B \cdot C \cdot D$
 - With four Boolean variables, how many Boolean expressions can be formed?
 - 16
 - 256
 - 1024 (1K)
 - 64 K (64×1024)
 - In signed magnitude representation, the binary equivalent of 22.5625 is (The bit before comma represents the sign)
 - 0, 10110.1011
 - 0, 10110.1001
 - 1, 10101.1001
 - 1, 10110.1001
 - Which of the following represent $'E3_{16}'$?
 - $(ICE)_{16} + (A2)_{16}$
 - $(IBC)_{16} - (DE)_{16}$
 - $(2BC)_{16} - (IDE)_{16}$
 - $(200)_{16} - (11D)_{16}$
 - In hexadecimal arithmetic, the result of $(77)_{16} - (3B)_{16}$ is equal to
 - $3D_{16}$
 - $3C_{16}$
 - 60_{16}
 - 73_{16}
 - A certain well known computer family represents the exponents of its floating point numbers as 'Excess-64' integers. Which one of the following number is represented by exponent $e_6 e_5 e_4 e_3 e_2 e_1 e_0$?
 - $e = -64 + \sum_{i=0}^6 2^i e_i$
 - $e = -64 + \sum_{i=0}^6 2e_i$
 - $e = 64 - \sum_{i=0}^6 2^i e_i$
 - $e = 64 - \sum_{i=0}^6 2e_i$
 - A 10-bit ADC with full-scale output voltage of 10.24 V is designed to have $a + \text{LSB}/2$ accuracy. If the ADC is calibrated at 25°C and the operating temperature ranges from 0°C to 50°C,

then the maximum net temperature coefficient of ADC should not exceed

- (a) $\pm 200 \mu V/^{\circ}C$ (b) $\pm 400 \mu V/^{\circ}C$
(c) $\pm 600 \mu V/^{\circ}C$ (d) $\pm 800 \mu V/^{\circ}C$

21. The characteristic equation for the next state (Q_{n+1}) of a J-K flip-flop is

- (a) $Q_{n+1} = JQ_n + K\bar{Q}_n$ (b) $Q_{n+1} = J\bar{Q}_n + KQ_n$
(c) $Q_{n+1} = J\bar{Q}_n + \bar{K}Q_n$ (d) $Q_{n+1} = JQ_n + KQ_n$

(where, Q_n represents the present state)

22. The number of unused states in a 4-bit Johnson counter is

- (a) 2 (b) 4
(c) 8 (d) 12

23. The output of a logic gate is '1' when all its inputs are at logic '0'. Then the gate is either

- (a) A NAND or an EX-OR gate
(b) A NOR or an EX-NOR gate
(c) An AND or an EX NOR gate
(d) Decrease the discharging time of C

24. The Boolean expression $(\bar{A} + B)(A + \bar{C})(\bar{B} + \bar{C})$ simplifies to

- (a) $(A + B)\bar{C}$ (b) $(A + \bar{B})\bar{C}$
(c) $(\bar{A} + B)\bar{C}$ (d) $(\bar{A} + \bar{B})\bar{C}$

25. The minimum number of NAND gates required to implement the Boolean function $A + A\bar{B} + A\bar{B}C$ is equal to

- (a) Zero (b) 1
(c) 4 (d) 7

26. The addition of two binary variables A and B results into a SUM and a CARRY output. Consider the following expressions for the SUM and CARRY outputs

1. $SUM = A \cdot B + \bar{A} \cdot \bar{B}$
2. $SUM = A \cdot \bar{B} + \bar{A} \cdot B$
3. $CARRY = A \cdot B$
4. $CARRY = A + B$

Which of these expressions are correct?

- (a) 1 and 3 (b) 2 and 3
(c) 2 and 4 (d) 1 and 4

27. For a binary half-subtractor having two inputs A and B, the correct sets of logical expressions for the outputs D (=A minus B) and X (=borrow) are:

- (a) $D = AB + \bar{A}\bar{B}, X = \bar{A}B$
(b) $D = \bar{A}B \bar{A}\bar{B}, X = \bar{A}\bar{B}$
(c) $D = \bar{A}B + \bar{A}\bar{B} + AB, X = \bar{A}\bar{B}$
(d) $D = AB + \bar{A}\bar{B}, X = A\bar{B}$

28. Minimum number of J-K flip-flops needed to construct a BCD counter is.

- (a) 2 (b) 3
(c) 4 (d) 5

29. Which one of the following statements is not correct?

- (a) An 8 input MUX can be used to implement any 4 variable function
(b) A 3 line to 8 line DEMUX can be used to implement any 4 variable function
(c) A 64 input MUX can be built using nine 8 input MUXs
(d) A 6 line to 64 line DEMUX can be built using nine 3 line to 8 line DEMUXs

30. The total number of 1's in a 15-bit shift register is to be counted by clocking into a counter which is preset to 0. The counter must have which one of the following?

- (a) 4-bits (b) 5-bits
(c) 160bits (d) 6-bits

31. Assume that only x and y logic inputs are available, and their complements $\bar{x}$ and $\bar{y}$ are not available. What is the minimum number of 2-inputs NAND gates required to implement $x \oplus y$?

- (a) 2 (b) 3
(c) 4 (d) 5

32. What is the minimum number of NAND gates required to implement $A + \bar{A}\bar{B} + \bar{A}BC$?

- (a) 0 (b) 1
(c) 4 (d) 7

33. The output of a two level AND-OR gate network is F. What is the output when all the gates are replaced by NOR gates?

- (a) F (b) $\bar{F}$
(c) F^D (d) $\bar{F}^D$

where F^D is the dual function of F

34. What is the octal equivalent of decimal 0.3125?

- (a) 0.42 (b) 0.3125
(c) 0.24 (d) 0.12

35. How many 1's are present in the binary representation of $(4 \times 4096) + (9 \times 256) + (7 \times 16) + 5$?

- (a) 8 (b) 9
(c) 10 (d) 11

36. Consider the following statements:

A 4 : 16 decoder can be constructed (with enabled input) by

1. Using four 2:4 decoders (each with an enabled input) only
2. Using five 2:4 decoders (each with an enabled input) only
3. Using two 3:8 decoders (each with an enabled input) only
4. Using two 3:8 decoders (each with an enabled input) and an inverter

Which of the statements given above is/are correct?

- (a) 2 and 3
(b) 1 only
(c) 2 and 4
(d) None of the above

37. The Boolean function $(x + y)(\bar{x} + z)(y + z)$ is equal to which one of the following expressions?

(a) $(x + y)(y + z)$ (b) $(\bar{x} + z)(y + z)$
(c) $(x + y)(\bar{x} + z)$ (d) $(x + y)(x + \bar{z})$

38. $AB + \bar{A}C = (A + C)(\bar{A} + B)$

Which one of the following is the dual form of the Boolean identity given above?

(a) $AB + \bar{A}C = AC + \bar{A}B$
(b) $(A + B)(\bar{A} + C) = (A + C)(\bar{A} + B)$
(c) $(A + B)(\bar{A} + C) = AC + \bar{A}B$
(d) $AB + \bar{A}C = AB + \bar{A}C + BC$

39. If $(2.3)_{\text{base } 4} + (1.2)_{\text{base } 4} = (y)_{\text{base } 4}$; What is the value of y ?

(a) 10.1 (b) 10.01
(c) 10.2 (d) 1.02

40. The number of 1 in 8-bits representation of -127 in 2's complement form is m and that in 1's complement form is n . What is n ? What is the value of m ; n ?

(a) 2 : 1 (b) 1 : 2
(c) 3 : 1 (d) 1 : 3

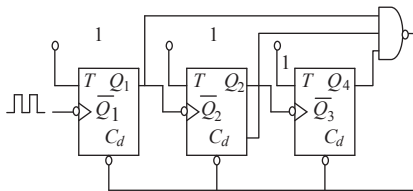
41. Given $(135)_{\text{base } x} + (144)_{\text{base } x} = (323)_{\text{base } x}$. What is the value of base x ?

(a) 5 (b) 3
(c) 12 (d) 6

42. 12 MHz clock frequency is applied to a cascaded counter of modulus -3 counter, modulus -4 counter and modulus -5 counter. What are the lowest output frequency and the overall modulus, respectively?

(a) 200 kHz, 60 (b) 1 MHz, 60
(c) 3 MHz, 12 (d) 4 MHz, 12

43. The circuit given below is that of a



(a) Mod -5 counter (b) Mod -6 counter
(c) Mod -7 counter (d) Mod -8 counter

44. A 1-bit full adder takes 20 ns to generate carry-out bit and 40 ns for sum bit. What is the maximum rate of addition per second when four 1-bit full adders are cascaded?

(a) 10^7 (b) 1.25×10^7
(c) 6.25×10^6 (d) 10^6

45. The Boolean expression $X(P, Q, R) = \pi(O, 5)$ is to be realized using only two 2-input gates. Which are these gates?

(a) AND and OR (b) NAND and OR
(c) AND and XOR (d) OR and XOR

46. What does the Boolean expression $AD + ABCD + ACD + \bar{A}B + A\bar{C}D + \bar{A}\bar{B}$, on minimization result into?

(a) $A + D$ (b) $AD + \bar{A}$
(c) AD (d) $\bar{A} + D$

47. If A and B are Boolean variable then what is $(A + B) \cdot (A + \bar{B})$ equal to?

(a) B (b) A
(c) $A + B$ (d) AB

48. What is the Boolean expression $A \oplus B$ equivalent to?

(a) $AB + \bar{A}\bar{B}$ (b) $\bar{A}B + A\bar{B}$
(c) B (d) $\bar{A}$

49. What is the Gray code word for the binary number 101011?

(a) 101011 (b) 110101
(c) 011111 (d) 111110

50. Which of the following subtraction operations do not result in F_{16} ?

1. $(BA)_{16} - (AB)_{16}$
2. $(BC)_{16} - (CB)_{16}$
3. $(CB)_{16} - (BC)_{16}$

Select the correct answer using the code given below:

(a) Only 1 and 2 (b) Only 1 and 3
(c) Only 2 and 3 (d) 1, 2 and 3

51. Which one of the following equations satisfies the JK flip-flop truth table?

(a) $Q_{n+1} = J_n \bar{Q}_n + \bar{K}_n Q_n$ (b) $Q_{n+1} = \bar{J}_n \bar{Q}_n + \bar{K}_n Q_n$
(c) $Q_{n+1} = J_n Q_n + K_n \bar{Q}_n$ (d) $Q_{n+1} = \bar{J}_n \bar{Q}_n + \bar{K}_n \bar{Q}_n$

52. What is the number of selector lines required in a single input n -output demultiplexer?

(a) 2 (b) n
(c) 2^n (d) $\log_2 n$

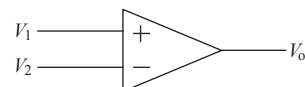
53. A master slave configuration consists of two identical flip-flops connected in such a way that the output of the master is input to the slave. Which one of the following is correct?

(a) Master is level triggered and slave is edge triggered
(b) Master is edge triggered and slave is level triggered
(c) Master is positive edge triggered and slave is negative edge triggered
(d) Master is negative edge triggered and slave is positive edge triggered

54. Which one of the following D/A converters has the resolution of approximately 0.4% of its full scale range?

(a) 8-bit (b) 10-bit
(c) 12-bit (d) 16-bit

55. How can the voltage comparator shown in the circuit given be used in the analog-to-digital conversion?



(a) As a 1-bit quantizer
(b) As a 2-bit quantizer

- (c) As a 4-bit quantizer
(d) As a 8-bit quantizer
56. A 10-bit A/D converter is used to digitize an analog signal in the 0 to 5 V range. What is the approximate value of the maximum peak to peak ripple voltage that can be allowed in the d.c. supply voltage?
(a) 100 mV (b) 50 mV
(c) 25 mV (d) 5.0 mV
57. In hexadecimal system, $(77)_{16} - (3B)_{16}$ is equal to
(a) $(3D)_{16}$ (b) $(60)_{16}$
(c) $(3C)_{16}$ (d) $(73)_{16}$
58. Which one of the following is the dual-form of the Boolean identity
 $AB + \bar{A}C = (A + C)(\bar{A} + B)$?
(a) $AB + \bar{A}C = AC + \bar{A}B$
(b) $(A + B) + (\bar{A} + C) = (A + C)(\bar{A} + B)$
(c) $(A + B)(\bar{A} + C) = AC + \bar{A}B$
(d) $AB + \bar{A}C = AB + \bar{A}C + BC$
59. A 4-bit D/A converter gives an output voltage of 4.5 for and input code of 1001. The output voltage for and input of 0.110 is
(a) 1.5 V (b) 2.0 V
(c) 3.0 V (d) 4.5 V
60. In successive-approximation A/D converter, offset voltage to $(1/2)$ LSB is added to the D/A converter's output. This is done to
(a) Improve the speed of operation
(b) Reduce the maximum quantization error
(c) Increase the number of bits at the output
(d) Increase the range of input voltage that can be converted
61. A D/A converter has 5 V full scale output voltage and an accuracy of $\pm 0.2\%$. The maximum error for any output voltage will be
(a) 5 mV (b) 10 mV
(c) 20 V (d) 25 mV
62. In a digital system, there are three inputs A , B and C . The output should be high when at least two input are high. The Boolean expression for the output is
(a) $AB + BC + AC$
(b) $ABC + ABC + \bar{A}BC + \bar{A}BC$
(c) $ABC + \bar{A}BC + \bar{A}BC$
(d) $\bar{A}B + \bar{B}C + \bar{A}C$
63. Which of the following standard TTL Parametre pairs are correctly matched?
1. Worst case high voltage at the input V_{IH} min.. 2 V
2. Fan out 40
3. Worst case output current at low level J_{OL} max 16 mA
4. Direct compatibility with CMOS..... NOT Possible
Select the correct answer using the codes given below
(a) 1, 2, 3 and 4 (b) 2 and 4
(c) 1, 2 and 3 (d) 1, 3 and 4
64. For the design of a sequential circuit having nine sates MINIMUM number of memory elements required is
(a) 3 (b) 4
(c) 5 (d) 9
65. A 4-bit binary ripple counter uses flip-flop with a propagation delay time of 25 ns each. The maximum possible time required for change of state will be
(a) 25 ns (b) 50 ns
(c) 75 ns (d) 100 ns
66. A 12-bit ADC is employed to converter an analog voltage of zero to 10 volts. The resolution of the ADC is
(a) 2.44 mV (b) 24.4 mV
(c) 83.3 mV (d) 1.2 V
67. In a 4-bit weighted-resistor D/A converter, the resistor value corresponding to LSB is 16 k Ω . The resistor value corresponding to the MSB will be
(a) 1 k Ω (b) 2 k Ω
(c) 4 k Ω (d) 16 k Ω
68. If 0, 1, 2, ..., \$, are the r digits in ascending order in a number system with radix r, then multiplied by will be
(a) 2 (b) 1
(c) 1\$ (d) \$1
69. The expression for the infix equivalent of the prefix form of $+ * \uparrow ABCD / E / F + GH$ will be
(a) $B^B * C - D + E \mid F \mid G + H$
(b) $A^B * CG - D + E \mid F \mid G + H$
(c) $A^B * C - D + E \mid F \mid G + H$
(d) $B^B * C - D + E \mid F \mid G + H$
70. The characteristic equation of an SR flip-flop is given by
(a) $Q^{n+1} = s + RQ_n$ (b) $Q^{n+1} = RQ_n + \bar{S}Q_n$
(c) $Q^{n+1} = \bar{S} + RQ_n$ (d) $Q_{n+1} = S + \bar{R}Q_n$
71. The access time of a word in a 4 MB main memory is 100 ns. The access time of a word in a 32 kB data cache memory is 10ns. The average data cache hit ratio is 0.95. The effective memory access time is
(a) 9.5 ns (b) 14.5 ns
(c) 20 ns (d) 95 ns
72. In 8086 microprocessor, if code segment contains 1 FAB and IP register contains 10A1, the erective memory address is
(a) 20 B 51 (b) 304C
(c) FBC0 (d) FDB5

73. To have multiprocessing capabilities of the 8086 microprocessor, the pin connected to the ground is

- (a) $\overline{DEN}$ (b) ALE
(c) $INTR$ (d) $MN/\overline{MX}$

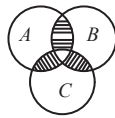
74. The Boolean theorem $AB + \overline{A}C + BC = AB + \overline{A}C$ corresponds to

- (a) $(A+B) \cdot (\overline{A}+C) \cdot (B+C) = (\overline{A}+C)(A+B)$
(b) $AB + \overline{A}C + BC = AB + BC$
(c) $AB + \overline{A}C + BC = (A+B) \cdot (\overline{A}+C) \cdot (B+C)$
(d) $(A+B) \cdot (\overline{A}+C) \cdot (B+C) = AB + \overline{A}C$

75. For a particular type of memory, the access time and the cycle are respectively 200 ns and 200 ns. The maximum rate at which the data can be accessed is

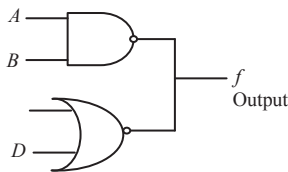
- (a) $2.5 \times 10^6/s$ (b) $5 \times 10^6/s$
(c) $0.2 \times 10^6/s$ (d) $10^6/s$

76. The Boolean expression for the shaded area in the given Venn diagram is



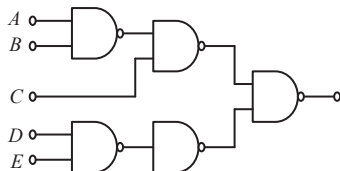
- (a) $AB + BC + CA$ (b) $\overline{A}BC + \overline{A}B\overline{C} + A\overline{B}C$
(c) $ABC + \overline{A}\overline{B}\overline{C}$ (d) $\overline{A}\overline{B}\overline{C} + A\overline{B}\overline{C}$

77. Which one of the following logic function is implemented by the gates when their open collector type output are tied together as shown in the given figure?



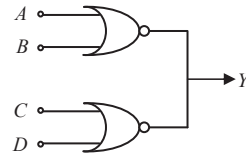
- (a) $f = AB + C + D$ (b) $f = \overline{AB} + (\overline{C} + D)$
(c) $f = \overline{AB + (C + D)}$ (d) $f = \overline{AB + C \cdot D}$

78. The circuit shown in the following figure realizes the function



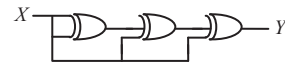
- (a) $(\overline{A} + \overline{B})C + \overline{DE}$ (b) $(A+B)C + D + E$
(c) $AB + C + DE$ (d) $AB + C(D + E)$

79. When two gates with open collector output are tied together as shown in the figure, the output obtained will be



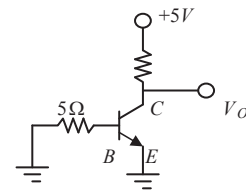
- (a) $\overline{A} + \overline{B} + \overline{C} + \overline{D}$ (b) $\overline{A} + \overline{B} + \overline{C} + \overline{D}$
(c) $(\overline{A} + \overline{B}) \cdot \overline{C} + \overline{D}$ (d) $(\overline{A} + \overline{B}) + (\overline{C} + \overline{D})$

80. The output Y of the given circuit is



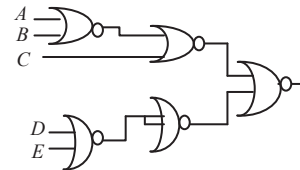
- (a) 1 (b) Zero
(c) X (d) $\overline{X}$

81. The voltage V_o of the circuits shown in the given figure is



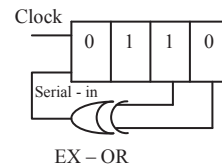
- (a) 5 V (b) 3.1 V
(c) 2.5 V (d) zero

82. The circuit shown in the given figure realizes the function



- (a) $(\overline{A} + \overline{B} + \overline{C})(\overline{D} \cdot \overline{E})$ (b) $(\overline{A} + \overline{B} + \overline{C})(D \cdot \overline{E})$
(c) $(A + B + C)(\overline{D} \cdot \overline{E})$ (d) $(A + B + C)(\overline{D} \cdot \overline{E})$

83. The initial contents of the 4-bit serial in parallel out, right shift, shift register as shown in figure above are 0110. After 3 clock pulses, the contents of the shift register will be



- (a) 0000 (b) 0101
(c) 1010 (d) 1110

84. A, B and C are three Boolean variables. Which one of the following Boolean expressions cannot be minimized any further?

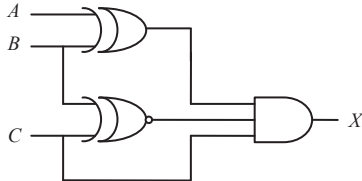
- (a) $Z = A \cdot \overline{B} \cdot \overline{C} + A \cdot B \cdot \overline{C} + A \cdot B \cdot C + \overline{A} \cdot \overline{B} \cdot \overline{C}$
(b) $Z = A \cdot \overline{B} \cdot C + A \cdot B \cdot \overline{C} + A \cdot B \cdot C + \overline{A} \cdot \overline{B} \cdot \overline{C}$

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- (c) $Z = A \cdot \overline{B} \cdot \overline{C} + \overline{A} \cdot \overline{B} \cdot C + A \cdot B \cdot C + \overline{A} \cdot B \cdot \overline{C}$
 (d) $Z = \overline{A} \cdot B \cdot \overline{C} + \overline{A} \cdot B \cdot C + A \cdot B \cdot C + \overline{A} \cdot \overline{B} \cdot C$

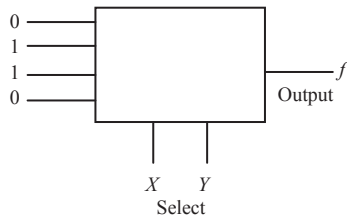
85. Consider the following logic circuit:

What is the required input condition (A, B, C) to make the output $X = 1$, for the above logic circuit?



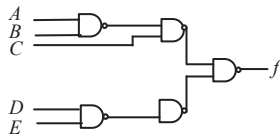
- (a) (1, 0, 1) (b) (0, 0, 1)
 (c) (1, 1, 1) (d) (0, 1, 1)

86. What is the output $f(x, y)$ of the multiplexer resulting from the input logical values?



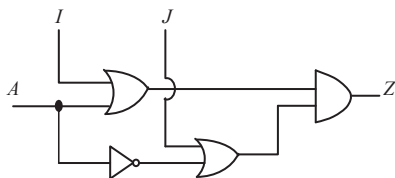
- (a) An EX-OR gate (b) A NOR gate
 (c) An AND gate (d) A NAND gate

87. Which one of the following functions is realized by the circuit shown below?



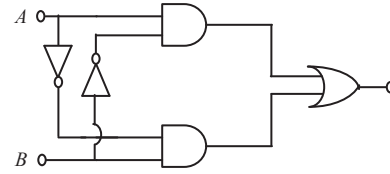
- (a) $(\overline{A} + \overline{B})C + \overline{DE}$
 (b) $(A + B)C + D + E$
 (c) $AB + C + DE$
 (d) $AB + C(D + E)$

88. The circuit shown above is to be used to implement the function $Z = f(A, B) = \overline{A} + B$. What values are to be selected for I and J?



- (a) $I = 1, J = B$ (b) $I = A, J = B$
 (c) $I = B, J = 1$ (d) $I = B, J = 0$

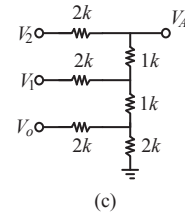
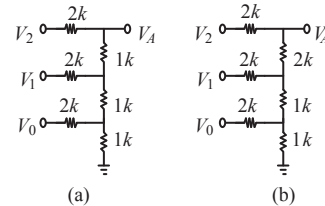
89. Which one of the following logic operations is performed by the digital circuit shown below?



- (a) NOR (b) NAND
 (c) EX-OR (d) OR

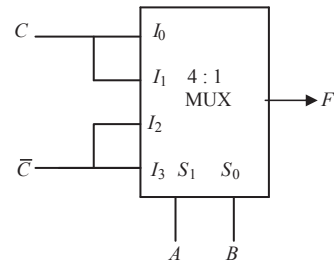
LEVEL 3

1. Which of the resistance network of figure can be used as 3 bit R-2R ladder DAC? Assume V_0 corresponds to LSB.



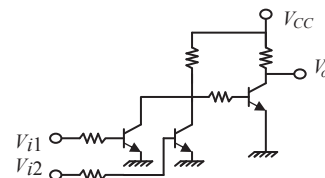
- (a) Both (a) and (b) (b) Both (a) and (c)
 (c) Only (c) (d) Only (b)

2. The logic realized by the circuit shown in figure is



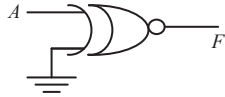
- (a) $F = A \ominus C$ (b) $F = A \oplus C$
 (c) $F = A + C$ (d) $F = B \oplus C$

3. Figure shows the circuit of a gate in the Resistor Transistor Logic (RTL) family. The circuit represent a



- (a) NAND (b) AND
 (c) NOR (d) OR

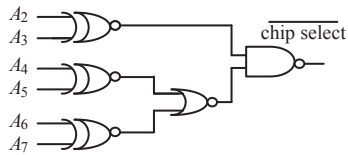
4. The output of the logic gate in this figure is



- (a) 0 (b) 1
(c) $\bar{A}$ (d) A

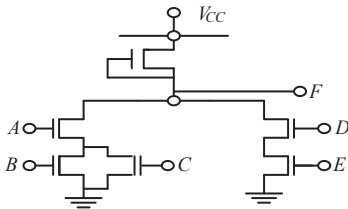
5. The decoding circuit shown in the figure has been used to generate the active low chip select signal for a microprocessor peripheral. (The address lines are designated as A_0 to A_7 for I/O addresses)

The peripheral will correspond to IO addresses in the range



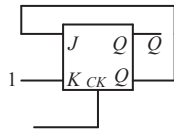
- (a) 60 H to 63 H (b) A 4 H to A 7 H
(c) 30 H to 33 H (d) 70 H to 73 H

6. For the NMOS logic gate shown in figure, the logic function implemented is



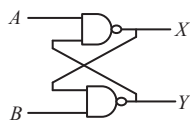
- (a) $\overline{ABCD}$ (b) $(AB + C)(\overline{D + E})$
(c) $\overline{A \cdot (B + C) + D \cdot E}$ (d) $\overline{(A + B) \cdot C + \overline{DE}}$

7. In a J-K flip-flop we have $J = Q$ and $K = 1$ in the given figure. Assuming the flip flop was initially cleared and then clocked for 6 pulses, the sequence at the Q output will be



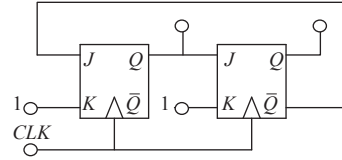
- (a) 010000 (b) 011001
(c) 010010 (d) 010101

8. In figure $A = 1$ and $B = 1$, the input B is now replaced by a sequence 101010----, the outputs x and y will be



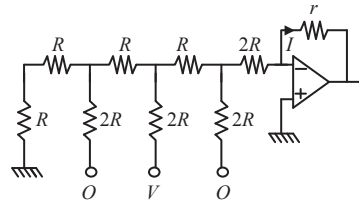
- (a) Fixed at 0 and 1, respectively
(b) $x = 1010$ ---- while $y = 0101$
(c) $x = 1010$ --- and $y = 1010$
(d) fixed at 1 and -0, respectively

9. Figure shows a mod -K-counter, Here K is equal to



- (a) 1 (b) 2
(c) 3 (d) 4

10. The current I through resistance r in the circuit shown in figure.



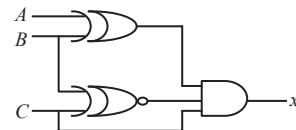
- (a) $-V / (12R)$
(b) $V / (12R)$
(c) $V / (6R)$
(d) $V / (3R)$

11. The K-map for a Boolean function is shown in the figure. The number of essential prime implicants for this function is

CD \ AB	00	01	11	10
00	1	1	0	1
01	0	0	0	1
11	1	0	0	0
10	1	0	0	1

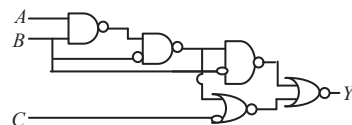
- (a) 4 (b) 5
(c) 6 (d) 8

12. For the logic circuit shown in the figure, the required input condition (A, B, C) to make the output (X) = 1 is



- (a) 1, 0, 1 (b) 0, 0, 1
(c) 1, 1, 1 (d) 0, 1, 1

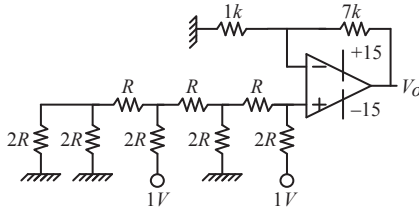
13. For the logic circuit shown in the figure, the simplified Boolean expression for the output Y is



- (a) $A + B + C$ (b) A
(c) B (d) C

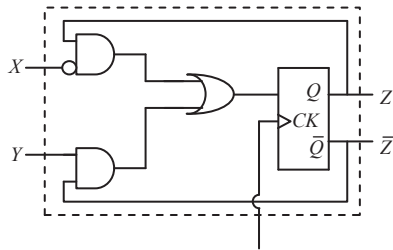
8.30 ■ Digital Electronic Circuits

14. For the 4 bit DAC shown in the figure, the output voltage V_o is



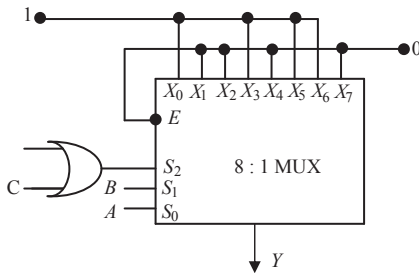
- (a) 10 V
(b) 5 V
(c) 4 V
(d) 8 V

15. A sequential circuit using D Flip-Flop and logic gates is shown in figure where X and Y are the inputs and Z is the output. The circuit is



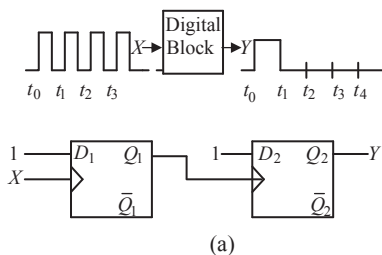
- (a) S-R Flip-Flop with inputs $X = R$ and $Y = S$
(b) S-R Flip-Flop with inputs $X = S$ and $Y = R$
(c) J-K Flip-Flop with inputs $X = J$ and $Y = K$
(d) J-K Flip-Flop with input $X = K$ and $Y = J$

16. In the TTL circuit in figure S_2 to S_0 are select lines and X_7 to X_0 are input lines. S_0 and X_0 are LSBs. The output Y is

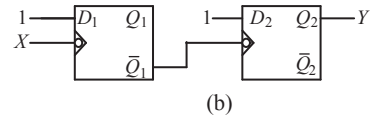


- (a) indeterminate
(b) $A \oplus B$
(c) $\overline{A \oplus B}$
(d) $\overline{C(A \oplus B)} + C \cdot (A \oplus B)$

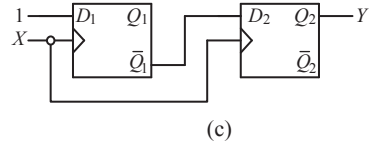
17. The digital block in figure is realized using two positive edge triggered D-flip-flops. Assume that for $t < t_0$, $Q_1 = Q_2 = 0$. The circuit in the digital block is given by



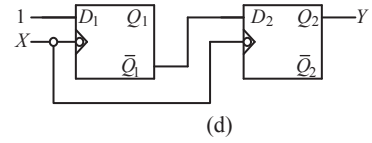
(a)



(b)



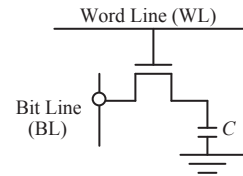
(c)



(d)

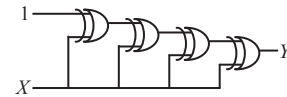
- (a) Figure (a)
(b) Figure (b)
(c) Figure (c)
(d) Figure (d)

18. In the DRAM cell in figure, the V_t of the MOSFET is 1V. For the following three combinations of WL and BL voltages $WL = 5V$, $BL = 5V$; $WL = 5V$, $BL = 3V$; $WL = 5V$, $BL = 7V$; The corresponding voltages across the capacitor C are



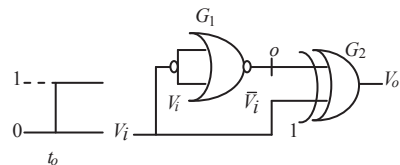
- (a) 5 V; 3 V; 7 V
(b) 4 V; 3 V; 4 V
(c) 5 V; 5 V; 5 V
(d) 4 V; 4 V; 4 V

19. If the input to the digital circuit shown in the figure consisting of a cascade of 20 XOR-gates is X , then the output Y is equal to



- (a) 0
(b) 1
(c) X
(d) $\overline{X}$

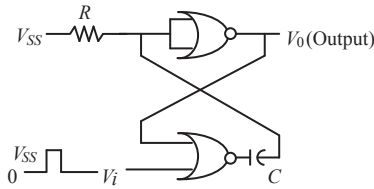
20. The gate G_1 and G_2 in Figure have propagation delays of 10 n sec and 20 n sec respectively. If the input V_i makes an abrupt change from logic 0 to 1 at time $t = t_0$, then the output waveform V_0 is



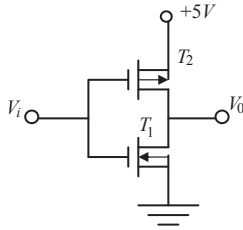
- (a)
(b)
(c)
(d)

$[t_1 = t_0 + 10 \text{ nsec}, t_2 = t_0 + 20 \text{ nsec}, t_3 = t_0 + 30 \text{ nsec}]$

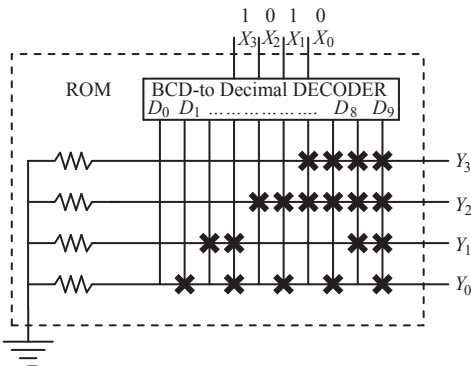
21. The circuit in figure has two CMOS NOR-gates. This circuit functions as a



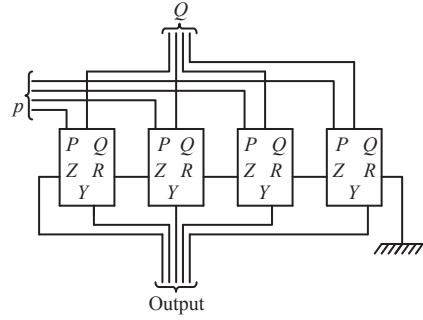
- (a) flip-flop
(b) Schmitt trigger
(c) monostable multivibrator
(d) astable multivibrator
22. Consider the following statements in connection with the CMOS inverter in figure where both the MOSFETs are of enhancement type and both have a threshold voltage of 2 V
- Statement 1:** T_1 conducts with $V_i \geq 2V$
Statement 2: T_1 is always in saturation when $V_o = 0V$
- Which of the following is correct?



- (a) Only Statement 1 is TRUE
(b) Only Statement 2 is TRUE
(c) Both the Statements are TRUE
(d) Both the Statements are FALSE
23. If the inputs $X_3X_2X_1X_0$ to the ROM in figure are 8-4-2-1 BCD numbers, then the outputs $Y_3Y_2Y_1Y_0$ are

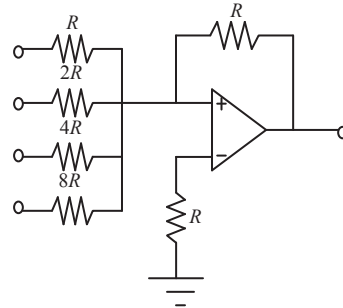


- (a) Gray code numbers (b) 2-4-2-1 BCD numbers
(c) excess-3 code numbers (d) none of the above
24. The circuit shown in the figure has 4 boxes each described by inputs P, Q, R and outputs Y, Z with
- $$Y = P \oplus Q \oplus R$$
- $$Z = RQ + \overline{P}R + Q\overline{P}$$

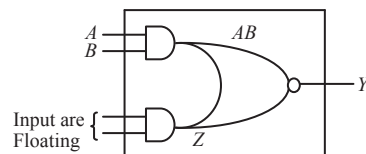


The circuit acts as a

- (a) 4 bit adder giving $P + Q$
(b) 4 bit subtractor giving $P - Q$
(c) 4 bit subtractor giving $Q - P$
(d) 4 bit adder giving $P + Q + R$
25. The circuit shown in the figure is a 4 bit DAC. The input bits 0 and 1 are represented by 0 and 5V respectively. The OP AMP is ideal, but all the resistances and the 5V inputs have a tolerance of $\pm 10\%$. The specification (rounded to the nearest multiple of 5%) for the tolerance of the DAC is

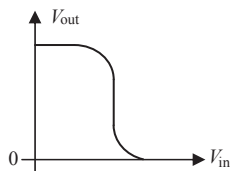


- (a) $\pm 35\%$ (b) $\pm 20\%$
(c) $\pm 10\%$ (d) $\pm 5\%$
26. The circuit shown in the figure converts
-
- (a) BCD to binary code (b) Binary to excess-3 code
(c) Excess-3 to Gray code (d) Gray to Binary code
27. Figure show the internal schematic of s **TTL AND-OR-invert (AOI)** gate. For the inputs shown in the figure, the output Y is



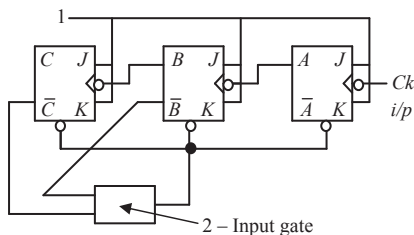
- (a) 0 (b) 1
(c) AB (d) $\overline{AB}$

28. Figure is the voltage transfer characteristic of



- (a) An NMOS inverter with enhancement mode transistor as load
- (b) An NMOS inverter with depletion mode transistor as load
- (c) A CMOS inverter
- (d) A BJT inverter

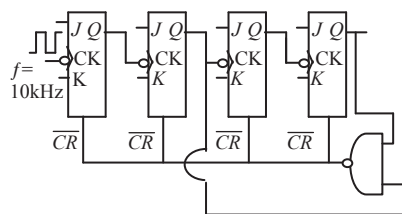
29. In the modulo-6 ripple counter shown in Figure, the output of the 2-input gate is used to clear the J-K flip-flops



The 2-input gate is

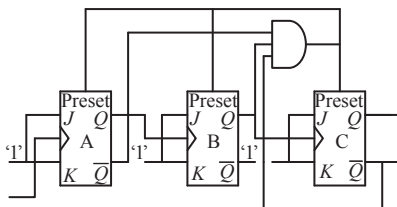
- (a) a NAND gate
- (b) a NOR gate
- (c) an OR gate
- (d) an AND gate

30. In figure, the J and K inputs of all the four Flip-Flops are made high. The frequency of the signal at output Y is



- (a) 0.833 kHz
- (b) 1.0 kHz
- (c) 0.91 kHz
- (d) 0.77 kHz

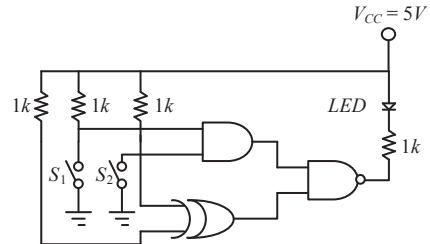
31. The ripple counter shown in the figure works as a



Clock

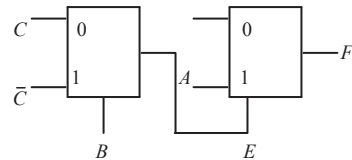
- (a) mod -3 up counter
- (b) mod -5 up counter
- (c) mod -3 down counter
- (d) mod -5 down counter

32. In figure the LED



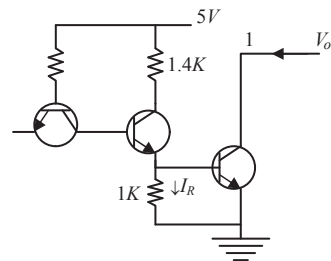
- (a) Emits light when both S_1 and S_2 are closed
- (b) Emits light when both S_1 and S_2 are open
- (c) Emits light when only of S_1 or S_2 is closed
- (d) Does not emit light, irrespective of the switch positions

33. The Boolean function f implemented in the figure using two input multiplexes is



- (a) $\bar{A}\bar{B}C + A\bar{B}\bar{C}$
- (b) $ABC + \bar{A}\bar{B}\bar{C}$
- (c) $\bar{A}BC + A\bar{B}\bar{C}$
- (d) $\bar{A}\bar{B}C + A\bar{B}\bar{C}$

34. The transistors used in a portion of the TTL gate shown in the figure have a $\beta = 100$. The base-emitter voltage of is 0.7 V for a transistor in active region and 0.75 V for a transistor in saturation. If the sink current $I = 1$ mA and the output is at logic 0, then the current I_R will be equal to



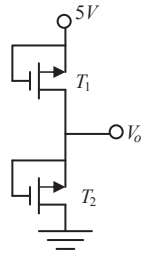
- (a) 0.65 mA
- (b) 0.70 mA
- (c) 0.75 mA
- (d) 1.00 mA

35. The Boolean expression for the truth table shown in

A	B	C	F
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	0

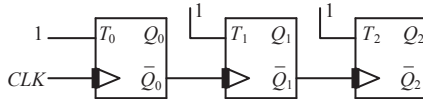
- (a) $B(A+C)(\bar{A}+\bar{C})$
 (b) $B(A+\bar{C})(\bar{A}+C)$
 (c) $\bar{B}(A+\bar{C})(\bar{A}+C)$
 (d) $\bar{B}(A+C)(\bar{A}+\bar{C})$

36. Both transistors T_1 and T_2 shown in the figure, have a threshold voltage of 1 volts. The device parameters K_1 and K_2 of T_1 and T_2 are, respectively, $36 \mu\text{A}/\text{V}^2$ and $9 \mu\text{A}/\text{V}^2$. The output V_0 is



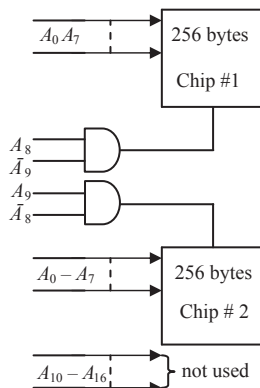
- (a) 1 V
 (b) 2 V
 (c) 3 V
 (d) 4 V

37. The given figure shows a ripple counter using positive edge triggered flip-flops. If the present state of the counter is $Q_2 Q_1 Q_0 = 011$, then its next state ($Q_2 Q_1 Q_0$) will be



- (a) 010
 (b) 100
 (c) 111
 (d) 101

38. What memory address range is NOT represented by chip # 1 and chip # 2 in the figure A_0 to A_{15} in this figure are the address lines and CS means Chip Select



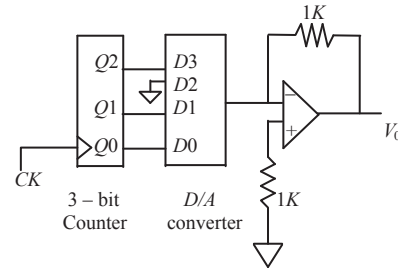
- (a) 0100-02FF
 (b) 1500-16FF
 (c) F900-FAFF
 (d) F800-F9FF

39. The number of product terms in the minimized sum of product expression obtained through the following K-map is (where, "d" denotes don't care states)

1	0	0	1
0	d	0	0
0	0	D	1
1	0	0	1

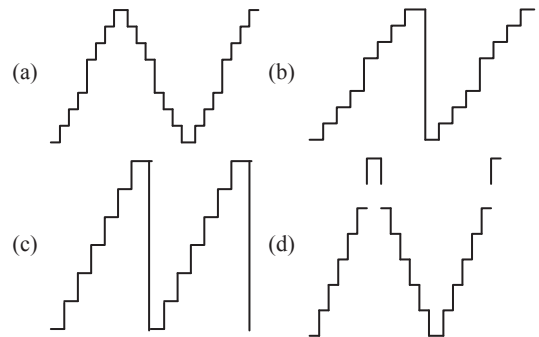
- (a) 2
 (b) 3
 (c) 4
 (d) 5

40. A 4-bit D/A converter is connected to a free-running 3-bit UP counter, as shown in the following figure. Which of the following waveforms will be observed at V_0 ?



In the figure shown above, the ground has been shown by the symbol ∇

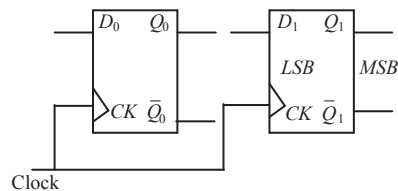
Figure



41. Two D-flip-flops as shown below, are to be connected as a synchronous counter that goes through the following $Q_1 Q_0$ sequence

$00 \rightarrow 01 \rightarrow 11 \rightarrow 10 \rightarrow 00 \rightarrow \dots$

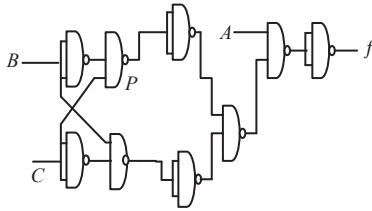
The inputs $D_0 D_1$ respectively should be connected as



- (a) $\bar{Q}_1$ and Q_0
 (b) $\bar{Q}_0$ and Q_1
 (c) $\bar{Q}_1 Q_0$ and $\bar{Q}_0 Q_0$
 (d) $\bar{Q}_1 \bar{Q}_0$ and $Q_1 Q_0$

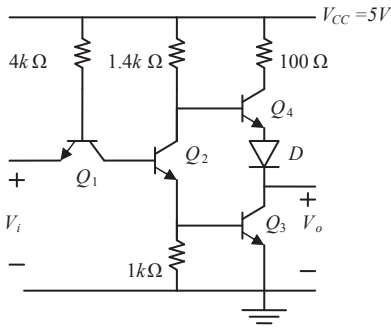
8.34 ■ Digital Electronic Circuits

42. The point P in the following figure is struck at -1 . The output f will be



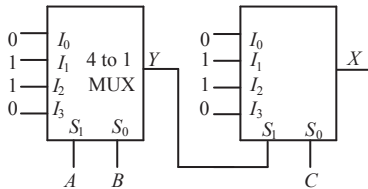
- (a) ABC (b) $\bar{A}$
(c) $AB\bar{C}$ (d) A

43. The circuit diagram of a standard TTL NOT gate is shown in the figure. When $V_i = 2.5V$, modes of operation of the transistors will be



- (a) Q_1 : reverse active ; Q_2 : normal active ;
 Q_3 : saturation ; Q_4 : cut-off ;
(b) Q_1 : reverse active ; Q_2 : saturation ;
 Q_3 : saturation ; Q_4 : cut-off ;
(c) Q_1 : normal active ; Q_2 : cut-off ;
 Q_3 : cut-off ; Q_4 : saturation ;
(d) Q_1 : saturation ; Q_2 : saturation ;
 Q_3 : saturation ; Q_4 : normal active ;

44. In the following circuit, X is given by

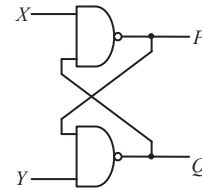


- (a) $X = A\bar{B}\bar{C} + \bar{A}B\bar{C} + \bar{A}\bar{B}C + ABC$
(b) $X = \bar{A}BC + A\bar{B}C + AB\bar{C} + \bar{A}\bar{B}\bar{C}$
(c) $X = AB + BC + AC$
(d) $X = \bar{A}\bar{B} + \bar{B}\bar{C} + \bar{A}\bar{C}$

45. The following binary values were applied to the X and Y inputs of the NAND latch shown in the figure in the sequence indicated below:

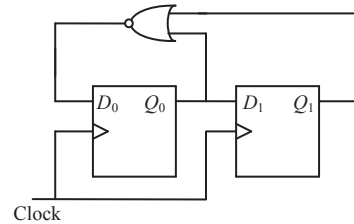
$X=0, Y=1$; $X=0, Y=0$; $X=1, Y=1$

The corresponding stable P, Q outputs will be



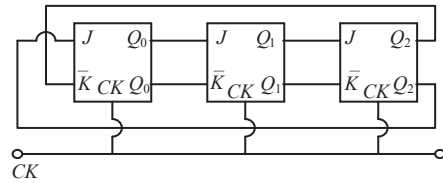
- (a) $P=1, Q=0$; $P=1, Q=0$ $P=1, Q=0$
or $P=0, Q=1$
(b) $P=1, Q=0$; $P=0, Q=1$ or $P=0, Q=1$
 $P=0, Q=1$
(c) $P=1, Q=0$; $P=1, Q=1$ $P=1, Q=0$
or $P=0, Q=1$
(d) $P=1, Q=0$; $P=1, Q=1$ $P=1, Q=0$

46. For the circuit shown, the counter state (Q_1, Q_0) follows the sequence



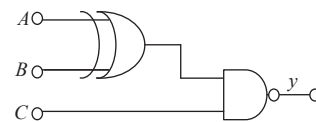
- (a) 00, 01, 10, 11, 00...
(b) 00, 01, 10, 00, 01...
(c) 00, 01, 11, 00, 01...
(d) 00, 10, 11, 00, 10...

47. The three stage Johnson ring counter shown in figure is clock at a constant frequency of f_0 from the starting state of $Q_0 Q_1 Q_2 = 101$. The frequency of outputs Q_0, Q_1, Q_2 will be



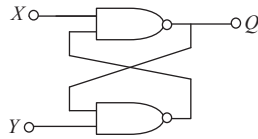
- (a) $f_c/2$ (b) $f_c/3$
(c) $f_c/6$ (d) $f_c/8$

48. The Boolean expression for the output for the logic circuit shown in the figure is



- (a) $Y = \bar{A}\bar{B} + AB + \bar{C}$ (b) $Y = \bar{A}\bar{B} + AB + \bar{C}$
(c) $Y = \bar{A}\bar{B} + \bar{A}\bar{B} + C$ (d) $Y = \bar{A}\bar{B} + \bar{A}\bar{B} + \bar{C}$

49. For a flip-flop formed from two NAND gates as shown in the figure, the unusable state corresponds to



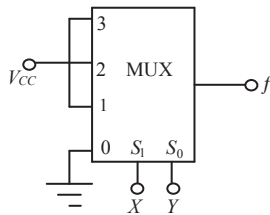
- (a) $X = 0, Y = 0$ (b) $X = 0, Y = 1$
 (c) $X = 1, Y = 0$ (d) $X = 1, Y = 1$

50. The minimal product-of-sums function described by the K-map given in figure

AB \ C	00	01	11	10
0	1	1	ϕ	0
1	0	0	ϕ	0

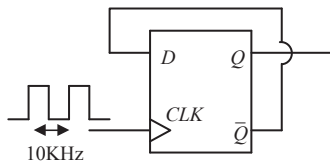
- (a) $A'C$ (b) $A' + C'$
 (c) $A + C$ (d) AC

51. The output f of the 4-to-1 MUX shown in the figure is



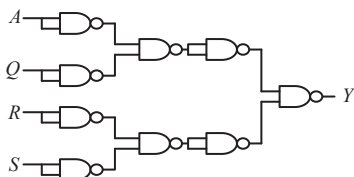
- (a) $xy + x$ (b) $x + y$
 (c) $\bar{x} + \bar{y}$ (d) $x\bar{y} + x$

52. The frequency of the clock signal applied to the rising edge triggered D flip-flop shown in the figure is 10 KHz. The frequency of the signal available at Q is



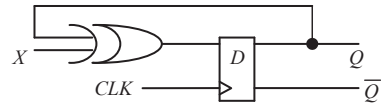
- (a) 10 KHz (b) 2.5 KHz
 (c) 20 KHz (d) 5 KHz

53. For the circuit shown in the figure, the Boolean expression for the output Y in terms of inputs P, Q, R and S is



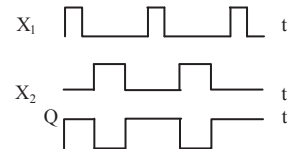
- (a) $\bar{P} + \bar{Q} + \bar{R} + \bar{S}$ (b) $P + Q + R + S$
 (c) $\bar{P} + \bar{Q} + \bar{R} + \bar{S}$ (d) $(P + Q)(R + S)$

54. The digital circuit shown in the figure works as a



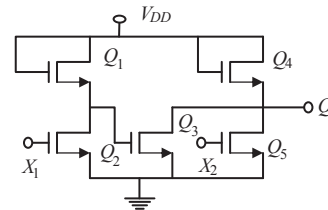
- (a) JK flip-flop (b) Clocked RS flip-flop
 (c) T flip-flop (d) Ring counter

55. Select the circuit which will produce the given output Q for the input signals X_1 and X_2 given in the figure



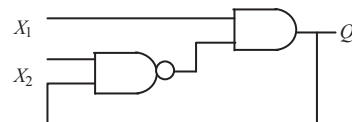
- (a) (b)
 (c) (d)

56. If X_1 and X_2 are the inputs to the circuit shown in the figure, the output Q is



- (a) $\bar{X}_1 + \bar{X}_2$ (b) $\bar{X}_1 \cdot \bar{X}_2$
 (c) $\bar{X}_1 \cdot X_2$ (d) $X_1 \cdot \bar{X}_2$

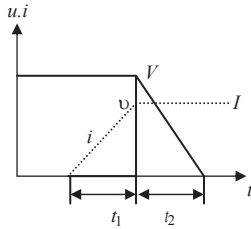
57. In the figure, as long as $X_1 = 1$ and $X_2 = 1$, the output Q remains



- (a) at 1 (b) at 0
 (c) at its initial value (d) unstable

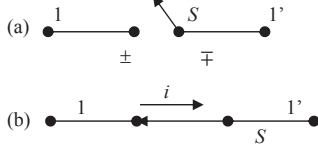
58. The figure shows the voltage across a power semiconductor device and the current through the device a switching

transitions. Is the transition a turn ON transition or a turn OFF transition? What is the energy lost during the transition?

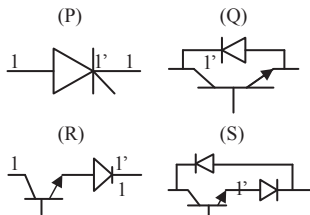


- (a) Turn ON, $\frac{VI}{2}(t_1 + t_2)$
 (b) Turn OFF, $VI(t_1 + t_2)$
 (c) Turn ON, $VI(t_1 + t_2)$
 (d) Turn OFF, $\frac{VI}{2}(t_1 + t_2)$

59. An electronic switch S is required to block voltages of either polarity during its OFF state as shown in the figure (a). This switch is required to conduct in only one direction during its ON state as shown in the figure (b).

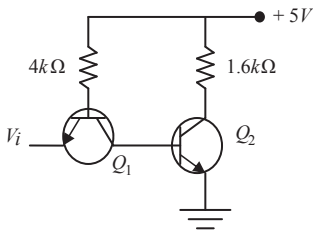


Which of the following are valid realizations of the Switch S ?



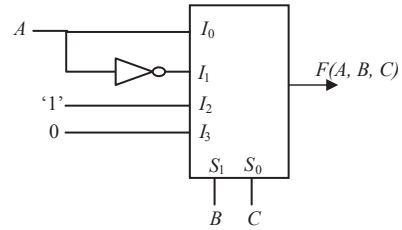
- (a) Only P
 (b) P and Q
 (c) P and R
 (d) R and S

60. A TTL NOT gate circuit is shown in figure. Assuming $V_{BE} = 0.7 \text{ V}$ of both the transistors, if $V_i = 3.0 \text{ V}$ then the states of the two transistors will be



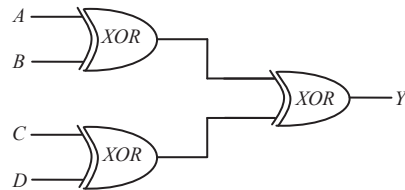
- (a) Q_1 ON and Q_2 OFF
 (b) Q_1 reverse ON and Q_2 OFF
 (c) Q_1 reverse ON and Q_2 ON
 (d) Q_1 OFF and Q_2 reverse ON

61. A 4×1 MUX is used to implement a 3-input Boolean function as shown in figure. The Boolean function $F(A, B, C)$ implemented is



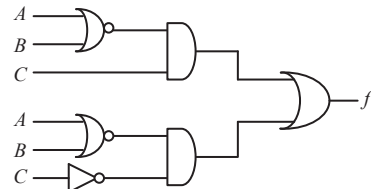
- (a) $F(A, B, C) = \Sigma(1, 2, 4, 6)$
 (b) $F(A, B, C) = \Sigma(1, 2, 6)$
 (c) $F(A, B, C) = \Sigma(2, 4, 5, 6)$
 (d) $F(A, B, C) = \Sigma(1, 5, 6)$

62. A, B, C and D are input bits, and Y is the output bit in the XOR gate circuit of the figure below. Which of the following statements about the sum S of A, B, C, D and Y is correct?



- (a) S is always either zero or odd
 (b) S is always either zero or even
 (c) $S = 1$ only if the sum of A, B, C and D is even
 (d) $S = 1$ only if the sum of A, B, C and D is odd

63. In the digital circuit shown in the figure, the output f is found to be logic 1 when A is logic '0'. The values of B and C are



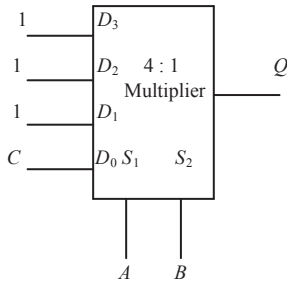
- (a) $B = 1, C = 0$
 (b) $B = 0, C = 0$ or 1
 (c) $B = 1, C = 1$
 (d) indeterminate

64. A combinational circuit has inputs A, B and C and its Karnaugh map is given in the figure. The output of the circuit is:

AB \ C	00	01	11	10
0		1		1
1	1		1	

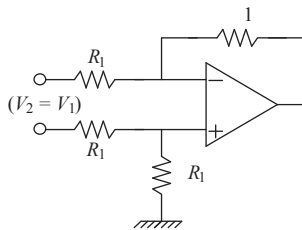
- (a) $(\bar{A}\bar{B} + AB)\bar{C}$
 (b) $(\bar{A}B + A\bar{B})C$
 (c) $A \oplus B \oplus C$
 (d) $\bar{A}\bar{B}\bar{C}$

65. The combinational circuit shown in the figure employs a 4 to 1 multiplexer. The output Q of the circuit is



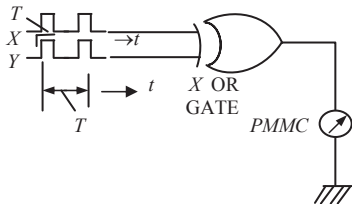
- (a) $\bar{A} \bar{B} C$ (b) $A + B + C$
 (c) $A \oplus B \oplus C$ (d) $\bar{A} \bar{B} \bar{C}$

66. The differential input resistance of the circuit shown in the figure is



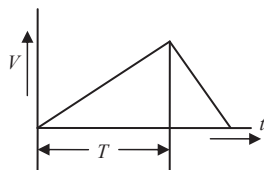
- (a) R_1 (b) $R_1/2$
 (c) $2R_1$ (d) R_f

67. For the two square inputs in figure the PMMC metre will read maximum when the phase difference between them is



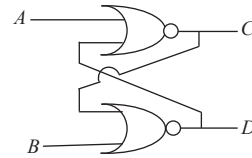
- (a) 0 (b) $\frac{T}{4}$
 (c) $\frac{T}{2}$ (d) T

68. Integrated output waveform for the dual slope ADC is shown in the figure. The time T for an 8 bit counter with 4 MHz clock will be



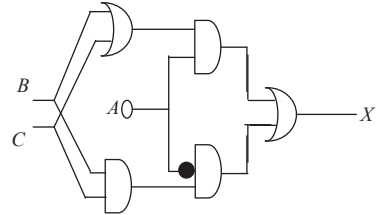
- (a) 0.032 ms (b) 0.064 ms
 (c) 0.64 ms (d) 0.024 ms

69. In the circuit shown in the figure, when inputs $A = B = 0$, the possible logic states of C and D are



- (a) $C = 0, D = 1$ or $C = 1, D = 0$
 (b) $C = 1, D = 1$ or $C = 0, D = 0$
 (c) $C = 1, D = 0$
 (d) $C = 0, D = 1$

70. In the logic circuit shown in the figure the output x is



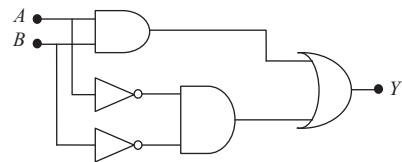
- (a) $\bar{A} \bar{B} + \bar{B} \bar{C} + \bar{C} \bar{A}$ (b) $A + B + C$
 (c) $AB + BC + CA$ (d) $\bar{A} \bar{B} + \bar{B} \bar{C} + \bar{C} \bar{A}$

71. The karnaugh map for a four variable Boolean function is given in. The correct Boolean sum of product is

PQ \ RS	00	01	11	10
00	0	0	0	0
01	1	0	0	1
11	1	0	0	1
10	0	1	0	0

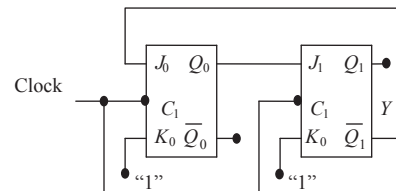
- (a) $PQRS + \bar{Q} S$ (b) $\bar{P} QR \bar{S} + \bar{Q} S$
 (c) $PQR + Q \bar{S}$ (d) $PQRS + Q$

72. The logic circuit of figure is a



- (a) Half adder (b) XOR
 (c) Equality detector (d) Full adder

73. The correct cyclic sequence of the output $s (Q_0 Q_1)$ for the JK master slave flip flop circuit shown in the figure when the input clock is applied is

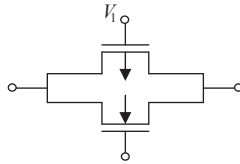


- (a) 00, 01, 10, 11, 00, 01, ...
 (b) 00, 10, 01, 00, 10, 01, ...

(c) 00, 01, 10, 00, 01, 10...

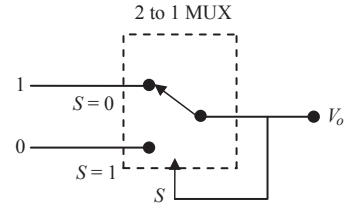
(d) 00, 11, 00, 11, 00, 11...

74. For the CMOS analog switch shown in the figure the positive supply is $+V_{DD}$ and the negative supply is $-V_{EE}$. The input V_i is bipolar. The switch will be ON and V_o will be equal to V_i provided



- (a) $V_1 = V_2 = +V_{DD}$
 (b) $V_1 = V_2 = -V_{EE}$
 (c) $V_1 = +V_{DD}$ and $V_2 = -V_{EE}$
 (d) $V_1 = -V_{EE}$ and $V_2 = +V_{DD}$

75. In 2 to 1 digital multiplexer a switching delay of $1\ \mu\text{s}$ is connected as shown in figure. The output of the multiplexer is tied to its own select input S. The input which gets selected when $S = 0$ is tied to 1 and the input that get is selected when $S = 1$ is tied to 0. The output V_o will be



- (a) 0
 (b) 1
 (c) Pulse train of frequency 0.5 MHz
 (d) Pulse train of frequency 1.0 MHz

ANSWER KEYS

LEVEL 1

1. (b)	2. (c)	3. (a)	4. (b)	5. (b)	6. (d)	7. (c)	8. (b)	9. (d)	10. (c)
11. (b)	12. (a)	13. (a)	14. (b)	15. (c)	16. (c)	17. (c)	18. (c)	19. (d)	20. (c)
21. (b)	22. (b)	23. (a)	24. (b)	25. (c)	26. (b)	27. (c)	28. (b)	29. (d)	30. (d)
31. (a)	32. (d)	33. (d)	34. (d)	35. (a)	36. (b)	37. (b)	38. (c)	39. (a)	40. (c)
41. (b)	42. (a)	43. (b)	44. (d)	45. (c)	46. (d)	47. (c)	48. (a)	49. (b)	50. (c)
51. (c)	52. (b)	53. (c)	54. (d)	55. (c)	56. (b)	57. (a)	58. (a)	59. (b)	60. (c)
61. (c)	62. (c)	63. (a)	64. (c)	65. (b)	66. (c)	67. (d)	68. (a)	69. (a)	70. (c)
71. (b)									

LEVEL 2

1. (c)	2. (a)	3. (a)	4. (a)	5. (b)	6. (a)	7. (b)	8. (c)	9. (c)	10. (b)
11. (b)	12. (d)	13. (a)	14. (a)	15. (b)	16. (d)	17. (b)	18. (a)	19. (a)	20. (c)
21. (c)	22. (b)	23. (c)	24. (a)	25. (b)	26. (c)	27. (c)	28. (d)	29. (c)	30. (d)
31. (a)	32. (c)	33. (c)	34. (a)	35. (c)	36. (a)	37. (c)	38. (c)	39. (a)	40. (a)
41. (d)	42. (a)	43. (a)	44. (d)	45. (d)	46. (b)	47. (b)	48. (d)	49. (b)	50. (a)
51. (d)	52. (c)	53. (d)	54. (a)	55. (a)	56. (d)	57. (a)	58. (c)	59. (c)	60. (d)
61. (b)	62. (a)	63. (d)	64. (b)	65. (d)	66. (a)	67. (b)	68. (d)	69. (d)	70. (d)
71. (b)	72. (a)	73. (d)	74. (a)	75. (d)	76. (b)	77. (b)	78. (a)	79. (d)	80. (b)
81. (a)	82. (a)	83. (c)	84. (c)	85. (d)	86. (a)	87. (a)	88. (a)	89. (c)	

LEVEL 3

1. (c)	2. (b)	3. (d)	4. (c)	5. (a)	6. (c)	7. (d)	8. (a)	9. (c)	10. (b)
11. (a)	12. (d)	13. (b)	14. (b)	15. (d)	16. (d)	17. (c)	18. (a)	19. (b)	20. (b)
21. (c)	22. (c)	23. (b)	24. (b)	25. (a)	26. (a)	27. (a)	28. (c)	29. (c)	30. (b)
31. (d)	32. (d)	33. (a)	34. (c)	35. (a)	36. (c)	37. (b)	38. (d)	39. (a)	40. (b)
41. (a)	42. (d)	43. (a)	44. (a)	45. (c)	46. (b)	47. (a)	48. (a)	49. (a)	50. (c)
51. (b)	52. (d)	53. (b)	54. (c)	55. (a)	56. (d)	57. (d)	58. (a)	59. (c)	60. (c)
61. (a)	62. (b)	63. (b)	64. (c)	65. (c)	66. (a)	67. (c)	68. (a)	69. (a)	70. (c)
71. (b)	72. (c)	73. (d)	74. (d)	75. (d)					

CONTROL SYSTEMS

9.1 CONTROL SYSTEM COMPONENTS

System: System is an arrangement of physical components connected or related in such a manner to form/or act as an entire unit.

Control: Means to regulate, direct or command.

Control System: A control system is a combination of components that are interconnected in a configuration design to provide a specified system in such a manner so as to command, direct or regulate itself or another system.

Feedback Control System: A control system that tends to maintain a prescribed relationship of one system variable to another by comparing functions of these variables and using the difference as a means of control.



Fig. 9.1 Process to be controlled

Controller or control actuator are utilized in order to obtain the desired response from the process.



Fig. 9.2 Process Controlled by Controller

9.2 BLOCK DIAGRAMMATIC DESCRIPTION

The combination of block diagram and transfer function of physical system provides a pictorial representation of the cause and

effect relationship between the output function and the input. Applied agent (cause) is excitation and corresponding reaction (effect) is response function.

Construction of Block Diagram Model: System function transforms the exciting function to response function.

$$\text{Excitation function} \times \text{System function} = \text{Response function}$$

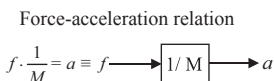


Fig. 9.3

For making block diagram of a system, its differential equations are written. By Laplace transform the equations are converted into algebraic ones, which can be put into block diagram.

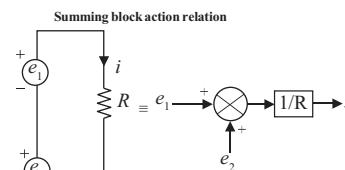


Fig. 9.4 (a)

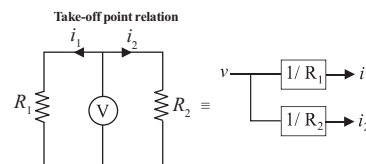


Fig. 9.4(b)

Feedback relation

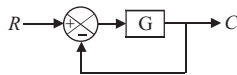


Fig. 9.5

Part of the excitation function may be derived directly or indirectly from the response function for taking part of response as excitation, a transfer block is used.

Block Diagram Reduction Technique

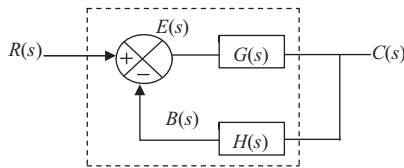


Fig. 9.6

$$G(s) = \frac{C(s)}{E(s)}; \quad H(s) = \frac{B(s)}{C(s)}$$

$$\frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)} = M(s)$$

This is the closed loop transfer function for negative feedback control system.

System can be reduced to a single block shown below:

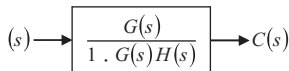


Fig. 9.7

Multiple Input-Output System Block Diagram

System shown with two inputs and two outputs. Using transfer function relations we can write the simultaneous equations for the output variable as

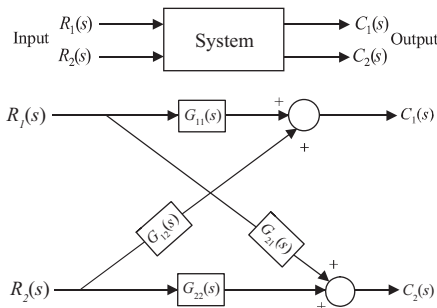


Fig. 9.8

$$C_1(s) = G_{11}(s) R_1(s) + G_{12}(s) R_2(s)$$

$$C_2(s) = G_{21}(s) R_1(s) + G_{22}(s) R_2(s)$$

For many inputs and outputs the equations can be put in matrix form

$$[C(s)] = [G][R]$$

9.3 OPEN LOOP AND CLOSED LOOP SYSTEMS

Open Loop Control System: These are control system in which the output has no effect upon the control action. The output is neither measured nor feedbacked for comparison with the input. Any system which operate on time basis is an open loop system. *Examples:* Traffic control set on time basis, washing machine or toaster operation.

Closed Loop Systems: Closed loop control system is one in which the output signal has a direct effect upon the control action. It is a feedback control system.

Closed Loop Control Systems	Open Loop Control Systems
1. Feedback applied	1. Feedback not applied
2. Response relatively insensitive precalibrated	2. Response is to external disturbance because of feedback
3. Stability of the system is always a major problem	3. Stability is not a major problem
4. Costly	4. Comparatively cheap

Types of Feedback Control System

Adaptive Control System: A proper combination of open loop and closed may be used where applicable. It is one which adjusts itself against environment, ageing deterioration and even engineering errors.

Multivariable Control System: It is a typical auto pilot system. The state of motion of vehicle (velocity, acceleration) fed to computer by means of motion sensors (gyros, acceleration metre). It tells the direction of vehicle or command from ground, computer generates signal which control the hydraulic actuator and in turn move the engine.

With time the system have become more complexed. The inter-relationship of many controlled variable must be considered in the control scheme. Block diagram depicts a multi variable control system.

System with more than one input and one or more output are called *multivariable control system*.

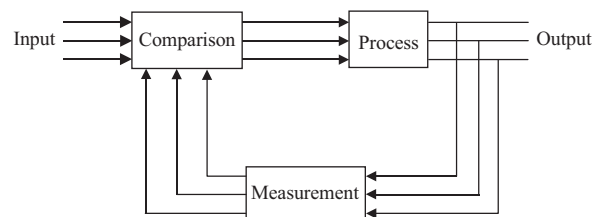


Fig. 9.9 Multivariable Control System

Servomechanisms: A Servomechanism is a feedback control system in which the output is some mechanical position, velocity or acceleration. The terms servomechanism and position or velocity or acceleration, control system are synonymous.

Characteristics of Feedback

The presence of feedback typically imparts the following properties to a system:

1. Increased accuracy. For example, the ability to faithfully reproduce the input. This property is illustrated through out the text.
2. Tendency towards oscillation or instability.
3. Reduced sensitivity of the ratio of output to input to variations in system parameters and other characteristics.
4. Reduced effects of non-linearities.
5. Reduced effects of external disturbances or noise.
6. Increased bandwidth. The bandwidth of a system is a frequency response measure of how well the system responds to (or filters) variations (or frequencies) in the input signal.

Stability

Stability in a system implies that small changes in the system input in initial conditions or in system parameters do not result in large changes in system output.

A linear time-invariant system is stable if the following notions of system stability are satisfied:

1. When the system is excited by a bounded input the output is bounded.
2. In the absence of the input, the output tends towards zero, irrespective of initial condition. This is known as *asymptotic stability*.

General Conclusions Regarding System Stability

1. If all the roots of the characteristic equation have negative real part, then the impulse response is bounded and eventually decreases to zero. The system is bounded-input, bounded-output *stable*.
2. If any root of characteristic equation has a positive part, the output is unbounded, so system is unstable.
3. If the characteristic equation has repeated roots on the $j\omega$ axis, output is unbounded and therefore, system is *unstable*.
4. If the first condition is satisfied except for the presence of one or more non-repeated roots on the $j\omega$ axis, the system is *limitedly stable or marginally stable*.

Types of Stability

- *Absolutely Stable* with respect to a parameter of the system, if it is stable for all values of this parameter.
- *Conditionally stable* with respect to a parameter, if the system is stable for only certain bounded ranges of value of this parameter.

Sensitivity

Feedback reduces the error. It reduces the sensitivity of the system due to parameter variation and unwanted internal and external disturbances. The parameters of a system have tendency to vary under a variety of changing condition, these parameters variation have adverse effect on system performance.

Reduction of Parameter Variation by the Use of Feedback

The beneficial effects of feedback in feedback system with high loop gain, which will be elaborated in this section, are enumerated below:

One of the primary purpose of using feedback in control systems is to reduce the sensitivity of the system to parameter variations. The parameters of a system may vary with age, with changing environment (e.g., ambient temperature), etc. Conceptually, sensitivity is a measure of the effectiveness of feedback in reducing the influence of these variations on system performance.

Let us define sensitivity on a quantitative basis. In the open-loop case

$$C(s) = G(s)R(s)$$

$$\Delta C(s) \approx \frac{\Delta G(s)}{1 + G(s)H(s)} R(s)$$

Sensitivity of Control Systems

The term *system sensitivity* is used to describe the relative variable in the overall function $T(s) = \frac{C(s)}{R(s)}$ due to variation in $C(s)$ and is defined below:

$$\text{Sensitivity} = \frac{\text{percentage change in } T(s)}{\text{percentage change in } G(s)}$$

For small incremental variation in $G(s)$, the sensitivity is written in the quantitative form as

$$S_G^T = \frac{\partial \ln T}{\partial \ln G} = \frac{(1/T) \delta T}{(1/G) \delta G} = \frac{\partial T/T}{\partial G/G}$$

where, S_G^T denotes the sensitivity of T with respect to G .

Sensitivity of Close Loop System

In accordance with the above definition, the sensitivity of the closed-loop system is

$$S_G^T = \frac{\partial T}{\partial G} \times \frac{G}{T} = \frac{(1 + GH) - GH}{(1 + GH)^2} \times \frac{G}{G/(1 + GH)} = \frac{1}{1 + GH}$$

Similarly, the sensitivity of the open-loop system is

$$S_G^T = \frac{\partial T}{\partial G} \times \frac{G}{T} = 1 \quad (\text{in this case } T = G) \quad \dots(2)$$

Thus, the sensitivity of a closed-loop system with respect to variation in G is reduced by a factor $(1 + GH)$ as compared to that of an open-loop system.

Sensitivity of $T(s)$ with Respect to $H(s)$

The sensitivity of T with respect to H , the feedback sensor, is given as

$$S_H^T = \frac{\partial T}{\partial H} \times \frac{H}{T} = G \left[\frac{-G}{(1 + GH)^2} \right] \frac{H}{G/(1 + GH)} = \frac{-GH}{1 + GH} \quad \dots(3)$$

9.4 SIGNAL FLOW GRAPHS

A signal flow graph may be regarded as simplified notation of block diagram as cause and effect representation of linear system. It is graphical representation of the relationship between the variables of a set of linear algebraic equations.

Signal Flow Graph Algebra

Based on the properties of the signal flow graph, we can outline the following manipulation and algebra of the signal flow graph.

1. The value of the variable represented by a node is equal to the sum of all the signals entering the node. Therefore, for the signal flow graph of figure given below the value of x_o is equal to the sum of the signals transmitted through all the incoming branches; i.e.,

$$x_o = t_{10} x_1 + t_{20} x_2 + t_{30} x_3$$

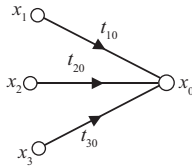


Fig. 9.10 Signal flow graph of $x_o = t_{10} x_1 + t_{20} x_2 + t_{30} x_3$

2. The value of the variable represented by a node is transmitted through all branches leaving the node. In the signal flow graph of figure given below, we have

$$x_1 = t_{n1} x_n$$

$$x_2 = t_{n2} x_n$$

$$x_3 = t_{n3} x_n$$

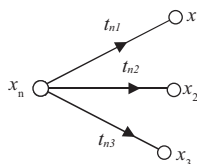


Fig. 9.11 Signal flow graph of equations, $x_1 = t_{n1} x_n$,

$$x_2 = t_{n2} x_n \text{ and } x_3 = t_{n3} x_n$$

3. Parallel branches in the same direction connecting two nodes can be replaced by a single branch with gain equal to the sum of the gains of the parallel branches.
4. A series connection of unidirectional branches, as shown in the figure below, can be replaced by a single branch with gain equal to the product of the branch gains.

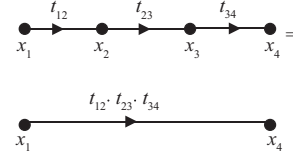


Fig. 9.12 Signal flow graph with cascaded unidirectional branches replaced by single branches

5. Signal flow graph of a feedback control system. Figure below shows the signal flow graph of a feedback control system. Therefore, the signal flow graph may be regarded as a simplified notation for the block diagram. Writing the equations for the signals at the nodes $E(s)$ and $C(s)$ we have

$$E(s) = R(s) - H(s) C(s) \text{ and } C(s) = G(s) E(s)$$

The closed-loop transfer function is obtained from these two equation,

$$\frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s) H(s)}$$

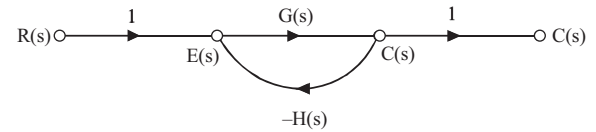


Fig. 9.13 Signal flow graph of a feedback control system.

Mason's Gain Formula

The relationship between an input variable and an output variable of a signal flow graph is given by the net gain between the input and output node and is also known as overall gain.

$$M = \frac{1}{\Delta} \sum_k P_k \cdot \Delta_k$$

where, M = overall system gain

P_k = path gain of k th forward path.

Δ = determinant of the graph

$= 1 - (\text{sum of loop gains of all individual loop})$

$+ (\text{sum of gain products of all possible combination of two non touching loop})$

$- (\text{sum of gain products of all possible combination of three non touching loop}) + \dots$

$$\Delta = 1 - \sum_m P_{m1} + \sum_m P_{m2} + \sum_m P_{m3} + \dots$$

where, P_{mr} = gain product of m th possible combination of r non-touching loop

Δ_k = The value of Δ for that part of the graph not touching the k th forward path.

9.5 TRANSIENT AND STEADY STATE ANALYSIS OF LTI CONTROL SYSTEMS AND FREQUENCY RESPONSE

Due to the application of an excitation to a system, the response of the system is known as *time response* and it is a function of time.

The time response of control system, i.e., feedback system is usually divided into two parts: The *transient response* and *steady state response*.

Let $c(t)$ denote a time response.

Then in general,

$$c(t) = c_t(t) + c_{ss}(t)$$

Transient response is defined as the part of the response that goes to zero as time becomes very large. Therefore, $c_t(t)$ has the property

$$\lim_{t \rightarrow \infty} c(t) = 0$$

It is a significant part of the dynamic behaviour of the system.

Steady state response is defined as the fixed response when time reaches infinity. The part of response that remains even after transients have died out is said to be steady-state response.

Example: sine wave, ramp function.

Time Response Specification

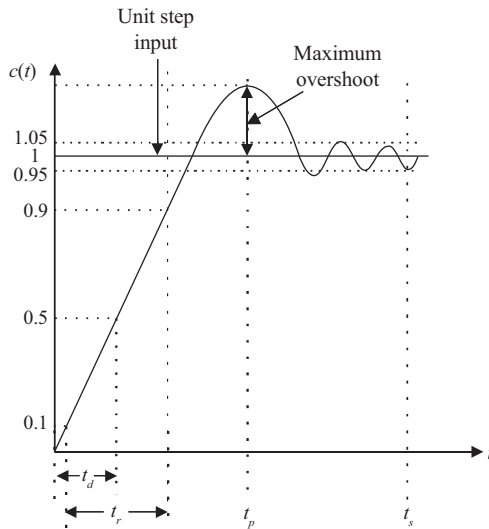


Fig. 9.14 Typical unit step response of a control system

Delay time t_d : It is the time required for the response to reach 50% of the final value in first attempt.

Rise time t_r : It is the time required for the response to rise from 10 to 90% of the final value for over damped system and 0 to 100% of the final value for under damped system.

Peak time t_p : It is the time required to reach the first peak of time response or the peak overshoot.

Peak overshoot M_p : It indicates the normalized difference between the time response peak and the steady output and defined as

$$\text{Peak percent overshoot} = \frac{C(t_p) - C(\infty)}{C(\infty)} \times 100\%$$

Setting time t_s : It is the time required for the response to each and stay within a specified tolerance (usually 2% or 5%) of its final value.

Steady-state error e_{ss} : It indicates the error between the actual output and desired output as t tends to infinity.

First Order System

First order system is characterized by the transfer function

$$X R(s) \rightarrow \left[\frac{K}{1 + sT} \right] \rightarrow C(s)$$

Fig. 9.15

$$\frac{C(s)}{R(s)} = \frac{K}{1 + Ts}$$

Second Order System

Some second order system and their transfer functions are given below:

Example: Series RLC circuit

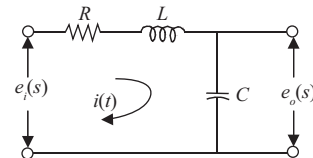


Fig. 9.16

$$\frac{E_o(s)}{E_i(s)} = \frac{1}{s^2 LC + sRC + 1}$$

The transfer function of a closed loop system that can be represented in the form

$$M(s) = \frac{p(s)}{q(s)} = \frac{k(s + z_1)(s + z_2) \dots (s + z_m)}{(s + p_1)(s + p_2) \dots (s + p_m)}$$

The denominator polynomial $q(s)$ when set equal to zero, is called **characteristic equation**, since the roots of this equation determine the character of the time response. The roots of this characteristic equation are called the **poles** or **singularities** of the system. The roots of the numerator polynomial $p(s)$ are called the zero of the system. **Poles** and the **zeros** are **critical** frequencies. As the poles the functions $M(s)$ becomes infinite, while at zeros, the function becomes zero. The complex frequency s -plane plot of poles and zeros graphically portrays the character of **natural transient response** of the system.

9.6 ■ Control Systems

A second order system is characterised by a characteristics equation of second degree

$$s^2 + 2\alpha s + (\alpha^2 + \omega_n^2) = 0$$

Which can be put in the form

$$s^2 + 2\delta\omega_n s + \omega_n^2 = 0$$

$$\alpha = \delta\omega_n$$

$$\alpha^2 + \omega_n^2 = \omega_n^2$$

δ is called **Damping ratio**.

The actual damping of a system is described by **damping constant** $\alpha = \delta\omega_n$

When $\alpha = 0$ there is no damping and the characteristic equation becomes (undamped system)

$$s^2 + \omega_n^2 = 0$$

Undamped frequency of the system ω_n is equal to the frequency which is the solution of this equation or natural frequency of oscillation.

Conditional frequency or actual frequency of system

$$\alpha^2 + \omega^2 = \omega_n^2$$

or

$$\omega^2 = \omega_n^2 - \alpha^2 = \omega_n^2(1 - \delta^2)$$

$$\omega = \omega_n \sqrt{1 - \delta^2}$$

The closed loop transfer function of a second order system is given by

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2} \quad \dots(1)$$

Assume that the denominator is factored as

$$s^2 + 2\delta\omega_n s + \omega_n^2 = (s - r_1)(s - r_2) \quad \dots(2)$$

The nature of the roots depends on the value of δ , the damping factor, as is evident from the expression

$$r_1, r_2 = (-\delta \pm \sqrt{\delta^2 - 1})\omega_n \quad \dots(3)$$

For $\delta > 0$: the roots r_1 and r_2 are **real valued** and in this case the system is called **over damped**.

For: the roots are complex conjugates and the system is called **under damped**.

For $\delta = 0$: the system is **undamped**

For $\delta < 0$: the roots will be in the right-half of the s-plane and the system is **negatively damped**.

If ω_n is constant, the roots of the characteristic equation vary as a function of δ . As δ varies from 0 to ∞ the location of roots will move away from imaginary axis along a circular path of radius ω_n . The roots will meet at a point $r_1, r_2 = -\omega_n$ and $\delta = 1$ and then separate and travel along the real axis towards zero and infinity.

For complex roots-under damped system the roots are $-\delta\omega_n \pm j\omega_n \sqrt{1 - \delta^2}$

For a case $\delta = 1$: the roots are repeated and are real and the condition is called **critical damping**.

The transient response becomes increasingly oscillatory as the roots approach imaginary axis, when δ approaches zero.

Impulse Response of Order System

The Laplace transform of output $C(s)$ for a unit impulse input $R(s) = 1$ is given by

$$C(s) = \frac{\omega_n^2}{r_1 - r_2} \left(\frac{1}{s - r_1} - \frac{1}{s - r_2} \right) \quad \dots(4)$$

This applies for $r_1 \neq r_2$, that is for $\delta \neq 1$. Substituting r_1 and r_2 and taking inverse Laplace transform, we get

$$c(t) = \frac{\omega_n e^{-\delta\omega_n t}}{2\sqrt{\delta^2 - 1}} \left[\exp(\sqrt{\delta^2 - 1}\omega_n t) - \exp(-\sqrt{\delta^2 - 1}\omega_n t) \right] \quad \dots(5)$$

For the over damped case $\delta > 1$ and $\sqrt{\delta^2 - 1}$ is real.

Step Response of Second Order System

Let input signal unit step $r(t) = u(t)$

The Laplace transform of $r(t)$ is given by

$$R(s) = \frac{1}{s}$$

For second order system

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

$$R(s) = \frac{\omega_n^2}{s(s^2 + 2\delta\omega_n s + \omega_n^2)}$$

$$C(s) = \frac{1}{s} - \frac{s + 2\delta\omega_n}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

$$c(t) = 1 - e^{-\delta\omega_n t} \cos \omega_d t - \frac{\delta}{\sqrt{1 - \delta^2}} e^{-\delta\omega_n t} \sin \omega_d t$$

$$c(t) = 1 - e^{-\delta\omega_n t} \left\{ \cos \omega_d t + \frac{\delta}{\sqrt{1 - \delta^2}} \sin \omega_d t \right\}$$

$$= 1 - \frac{e^{-\delta\omega_n t}}{\sqrt{1 - \delta^2}} \sin \left(\omega_d t + \tan^{-1} \frac{\sqrt{1 - \delta^2}}{\delta} \right)$$

Where $\cos \alpha = \delta$, $\sin \alpha = \sqrt{1 - \delta^2}$ and

$$\alpha = \tan^{-1} \frac{\sqrt{1 - \delta^2}}{\delta}$$

Delay time (T_d): The time required to reach 50% of output is known as delay time

$$\therefore c(t) = \frac{1}{2} \text{ at } t = T_d$$

From equation

$$\frac{1}{2} = 1 - \frac{e^{-\delta\omega_n T_d}}{\sqrt{1-\delta^2}} \sin \left[\omega_d T_d + \left(\tan^{-1} \frac{\sqrt{1-\delta^2}}{\delta} \right) \right]$$

The result of this equation is

$$T_d = \frac{1 + 0.7\delta}{\omega_n}$$

Rise time (T_r): Since the system is under damped, therefore,

From equation

$$c(t) = 1 \text{ at } t = T_r,$$

$$1 = 1 - \frac{e^{-\delta\omega_n T_r}}{\sqrt{1-\delta^2}} \sin \left(\omega_d T_r + \tan^{-1} \frac{\sqrt{1-\delta^2}}{\delta} \right)$$

$$T_r = \frac{-\tan^{-1} \left(\frac{\sqrt{1-\delta^2}}{\delta} \right)}{\omega_d}$$

$$T_r = \frac{\pi - \alpha}{\omega_d}$$

Peak time (T_p): Differentiating Equation $c(t) = 1 - \frac{e^{-\delta\omega_n t}}{\sqrt{1-\delta^2}} \sin(\omega_d t + \alpha)$ w.r.t. time, we get

$$\frac{dc(t)}{dt} = 0 - \frac{e^{-\delta\omega_n t} (-\delta\omega_n) \sin(\omega_d t + \alpha)}{\sqrt{1-\delta^2}} + \frac{e^{-\delta\omega_n t} \times \omega_d \cos(\omega_d t + \alpha)}{\sqrt{1-\delta^2}}$$

Putting $\frac{dc(t)}{dt} = 0$ and $t = T_p$, we get

$$\therefore T_p = \frac{n\pi}{\omega_d}$$

The first overshoot is obtained for $n = 1$ and the second overshoot is obtained for $n = 2$.

Peak overshoot (M_p): (M_p) is given by

$$M_p = c(t) \Big|_{t=T_p} - 1$$

$$\therefore c(t) \Big|_{t=T_p} = 1 - \frac{e^{-\delta\omega_n T_p}}{\sqrt{1-\delta^2}} \sin(\omega_d T_p + \alpha)$$

Putting $\omega_d T_p = \pi$

$$M_p = e^{-\delta\omega_n T_p} = e^{-\delta\omega_n \left(\frac{\pi}{\omega_d} \right)} = e^{-\delta\omega_n \left(\frac{\pi}{\omega_n \sqrt{1-\delta^2}} \right)} = e^{\frac{-\delta\pi}{\sqrt{1-\delta^2}}}$$

The value of M_p in percent is given by

$$\% M_p = e^{\frac{-\delta\pi}{\sqrt{1-\delta^2}}} \times 100$$

Settling time (T_s): For a 2% criterion,

$$T_s = 4T$$

$$\therefore T_s = \frac{4}{\delta\omega_n}$$

For 5% criterion $T_s = 3T$

where, $\frac{1}{\delta\omega_n} = T = \text{time constant.}$

Steady State Error and Error Constants

A simple closed-loop system using negative feedback is shown in the figure below:

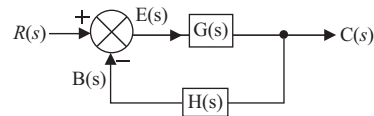


Fig. 9.17

In this figure, $R(s)$ is the Laplace transform of the applied input $C(s)$ is the Laplace transform of the output, $E(s)$ is the Laplace transform of the error signal and $B(s)$ is the Laplace transform of the feedback signal.

From above figure, we have

$$\therefore E(s) = \frac{R(s)}{1 + G(s)H(s)}$$

For unity feedback

$$E(s) = \frac{R(s)}{1 + G(s)}$$

If $R(s)$ is input and $G(s)$ open loop gain then steady state error for unity feedback system is given by

$$e_{ss} = \lim_{t \rightarrow \infty} e(t) = \lim_{s \rightarrow 0} sE(s) = \lim_{s \rightarrow 0} \frac{sR(s)}{1 + G(s)}$$

where, $e(t)$ = error signal = $r(t) - c(t)$

$r(t)$ = input signal

$c(t)$ = output of unity feedback system

(i) **Unit Step Input:** $R(s) = (1/s)$

$$e_{ss} = \lim_{s \rightarrow 0} \frac{s(1/s)}{1 + G(s)} = \frac{1}{1 + G(0)} = \frac{1}{1 + K_p}$$

where, $K_p = G(0)$ is defined as the *positional error constant*.

(ii) **Unit-Ramp (Velocity) Input:**

$$R(s) = \frac{1}{s^2}$$

$$e_{ss} = \lim_{s \rightarrow 0} \frac{s(a/s^2)}{1 + G(s)} = \frac{1}{K_v}$$

where, $K_v = \lim_{s \rightarrow 0} sG(s)$ is known as *velocity error constant*.

(iii) **Unit-Parabolic (Acceleration) Input:**

$$R(s) = \frac{1}{s^3} r(t) = \frac{r^2}{2}$$

$$e_{ss} = \lim_{s \rightarrow 0} \frac{s(1/s^3)}{1 + G(s)} = \frac{1}{\lim_{s \rightarrow 0} (s^2 G(s))} = \frac{1}{K_a}$$

where, $K_a = \lim_{s \rightarrow 0} s^2 G(s)$ is defined *acceleration error constant*.

Types of Feedback Control System

Since the error constant for a given system with unity feedback depends on the type of $G(s)$. $G(s)$ are classified as

$$G(s) = \frac{K(1 + S\tau_1)(1 + S\tau_2)}{S^n(a + S\tau_a)(1 + S\tau_b)}; \quad n = 0, 1, 2$$

where, K and τ are constant.

The type of control system referred to the order of the pole of $G(s)$ at $s = 0$. Therefore, the system that is described by $G(s)$ is of type n where, $n = 0, 1, 2, \dots$

$n = 0$, Type 0 system

$n = 1$, Type 1 system

9.6 TOOLS AND TECHNIQUES FOR LTI CONTROL SYSTEM ANALYSIS

Necessary Conditions for Stability are Obtained from Characteristic Equation

Consider the characteristic equation:

$$q(s) = a_n s^n + a_{n-1} s^{n-1} + \dots + a_1 s + a_0 = 0$$

- Necessary (but not sufficient) condition for stability of a linear system is that all the coefficient of its characteristic equation be real and have the same sign.
- From above $q(s)$, $a_n > 0$.
- If the characteristic equation of a system is of degree higher than second, the possibility of instability cannot be excluded even when all the coefficients of its characteristics equation are positive.

Routh's Stability Criterion

This criterion is based on ordering the coefficients of the characteristic equation into an array, called the Routh-array. For the characteristic equation,

$$q(s) = a_n s^n + a_{n-1} s^{n-1} + \dots + a_1 s + a_0 = 0$$

The method of forming the array is given below:

Routh array:

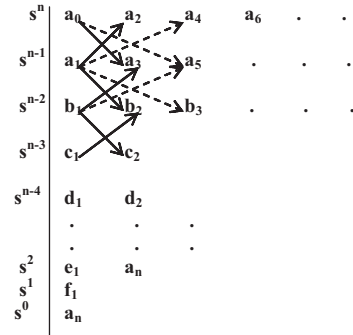


Fig. 9.18

For s^{n-2} the coefficient $b_1, b_2, \dots$ are evaluated as follow:

$$b_1 = \frac{a_1 a_2 - a_0 a_3}{a_1}; \quad b_2 = \frac{a_1 a_4 - a_0 a_5}{a_1}$$

$$c_1 = \frac{b_2 a_3 - a_1 b_2}{b_1}; \quad c_2 = \frac{b_1 a_5 - a_0 a_5}{b_1}$$

The process is continued until s^0 is obtained which is equal to a_n .

For a system to be stable, it is necessary and sufficient that each term of first column of Routh array of its characteristic equation should have same sign and there should not be any change of sign.

If this condition is not met, the system is unstable and number of sign changes of the terms of the first column of the Routh array corresponds to the no of roots of the characteristic equation in the right half of the s -plane.

Special Cases

In applying the Routh stability criterion, certain difficulties arise causing the breakdown of the Routh's test.

Difficulty 1: When the first term in any row of the Routh array is zero while rest of the row has at least one non-zero term. Due to this, the term in the next row becomes infinite and test breaks out. It can be solved by:

- Put a small positive number ϵ for the zero and proceed to evaluate the rest of the Routh array. Then examine the signs of the first column of Routh array by letting $\epsilon \rightarrow 0$.
- Modify the original characteristic equation by replacing S by $(1/P)$ and then apply the Routh test on the modified equation in term of P .
- Multiply the characteristic equation by $(s + 1)$ and proceed by Routh's method for checking of stability.

Difficulty 2: When all the elements in any one row of the Routh array are zero.

- This condition indicates that there are symmetrically located roots in the s -plane.

This shown symmetry located roots in s -plane pair of red roots with opposite sign and/or pair of conjugate roots on the imaginary axis and/or complex conjugate roots forming quadrature in the s -plane.

- The polynomial whose coefficient are the elements of the row just above the row of zero in the Routh array is called an *auxiliary polynomial*.

Construct an auxiliary polynomial using coefficient of row prior to zero row encountered.

Differentiate with s and put the coefficient of the this equation at a place where coefficient are zero, solve further as used.

9.7 THE ROOT LOCUS

Closed loop transfer function is expressed as

$$\frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

Characteristic equation of closed loop control system is $1 + G(s)H(s) = 0$... (1)

- The Conventional **root locus plots** includes the loci or the roots of characteristic equation when the gain K is varied from zero to infinity i.e., K is positive.
- **Root Contours (RC)**: Loci of roots when more than one parametre varies.
- **Complementary Root Loci (CRL)**: The portion of the root locus when K varies from $-\infty$ to 0 ; i.e., K is negative.
- **Root Locus (RL)**: There are plots of the variation of poles of the closed loop function (as obtained from characteristic equation) with variation in the open loop gain (changed from zero to infinity).

The complete root loci refers to the combination of the root loci and the complementary root loci that is when K varies from $-\infty$ to ∞ .

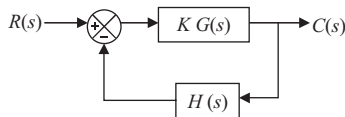


Fig. 9.19 A simple closed loop system

$$\frac{C(s)}{R(s)} = \frac{KG(s)}{1 + K G(s)H(s)}$$

Characteristic equation is $1 + K G(s)H(s) = 0$

$G(s)H(s)$ is a rational algebraic function can be put in terms of zero and pole factor.

$$G(s)H(s) = \frac{K \sum_{i=1}^Z (s - z_i)}{\sum_{j=1}^P (s - p_j)}$$

Where, z_i are zero

p_j are Poles

Characteristic equation can be written as

$$1 + G(s)H(s) = 0$$

$$\sum_{j=1}^P (s - p_j) + K \sum_{i=1}^Z (s - z_i) = 0$$

Construction of Complete Root Loci

The following rules of construction are developed from the relation between the poles and zeros of $G(s)H(s)$ and the zeros $1 + G(s)H(s)$. These rules should be regarded only as an aid to the construction of the RL and CRL.

1. **$K = 0$ Points**: The $K = 0$ points on the complete root loci are the poles of $G(s)H(s)$. (The poles include those at infinity).

$$\sum_{j=1}^P (s - p_j) + K \sum_{i=1}^Z (s - z_i) = 0$$

$$\sum_{i=1}^Z (s - z_i) = 0$$

$K = 0$, is the starting point of RL so poles of $G(s)H(s)$ provides the starting point for the root locus.

2. **$K = \pm \infty$ Point**: The $K = \pm \infty$ points on the complete root loci are at the zeros of $G(s)H(s)$. (The zero include those as infinity).

$$\sum_{j=1}^P (s - p_j) + K \sum_{i=1}^Z (s - z_i) = 0$$

$$\sum_{i=1}^Z (s - z_i) = 0$$

$K = \infty$, is the end point of locus, so zero of $G(s)H(s)$ provide the termination of root locus.

3. **Number of Separate Root Loci or Branches on the Complete Root Loci**: A branch of the complete root loci is the locus on one root when K takes on values between $-\infty$ and ∞ . Since the number of branches of the complete root loci must equal to the number of roots of the equation,

The total number of root loci is equal to the order of the characteristic equation:

N = Number of branch of RL

P = Number of finite Pole of $G(s)H(s)$

Z = Number of finite zero of $G(s)H(s)$

$N = Z$ if $Z > P$

$= P$ if $P > Z$

4. **Symmetry of the Complete Root Loci**

1. Root locus is symmetrical to the real axis of the s -plane.
2. In general the complete root loci are symmetrical with respect to the axis of symmetry of the poles and zero of $G(s)H(s)$.

The complete root loci are symmetrical with respect to the real axis of the s -plane. In general, the complete root loci are symmetrical with respect to the axis of symmetry of the poles and zeros of $G(s)H(s)$.

5. **Asymptotes of the Complete Root Loci (i.e., behaviour of root loci at $s = \infty$)**: The properties of the complete root

loci near infinity in the s -plane are important, since when $P \neq Z$, $2|P - Z|$ of the loci will approach infinity in the s -plane.

For large value of s , the RL ($K \geq 0$) are asymptotic to straight lines or asymptotes with angle value

$$\theta_q = \frac{(2q+1)\pi}{P-Z}$$

where, $q=0, 1, 2, \dots, \lceil (P-Z)-1 \rceil$ and P and Z are total number of **poles and zeros** of $G(s)H(s)$, respectively.

Number of asymptotes for $P - Z$

For CRL, $K \leq 0$, the angle of asymptotes are

$$\theta_q = \frac{2q\pi}{P-Z}$$

where, $q = 0, 1, 2, \dots, \lceil (P-Z)-1 \rceil$

According to the defining equations of the root loci, $q = 0, \pm 1, \pm 2, \dots$. However, since there are only $|P - Z|$ asymptotes for each type of root loci, we need to assign only $|P - Z|$ values to q .

6. Intersection of the Asymptotes (Centroid):

1. The intersection of the $2|P - Z|$ asymptotes lies only on the real axis in the s -plane.
2. The intersection of the asymptotes is given by

$$\sigma = \frac{b_1 - a_1}{P - Z}$$

$$\begin{aligned} & \Sigma \text{ finite poles of } G(s)H(s) - \Sigma \text{ finite zeros of } G(s)H(s) \\ &= \frac{\Sigma \text{ finite poles of } G(s)H(s) - \Sigma \text{ finite zeros of } G(s)H(s)}{\text{Number of finite poles of } G(s)H(s) - \text{Number of finite zeros of } G(s)H(s)} \end{aligned}$$

7. Root Loci on the Real Axis:

- (a) *Root loci*: On a given section of real axis the root loci $K \geq 0$ are found in the section only if the total number of real poles and zeros of $G(s)H(s)$ to the right of section is odd.
- (b) *Complementary root loci*: On a given section of the real axis, CRL $K \leq 0$ are found in the section only if the total number of real poles and zeros of $G(s)H(s)$ to the right of the section is even. Alternatively, we can state that CRL will be found in sections on the real axis not occupied by the root loci.

In all cases the complex poles and zeros of $G(s)H(s)$ do not affect the existence properties of the root loci on the real axis.

8. **Angle of Departure (from Pole) and Angle of Arrival (at zero) of the Complete Root Loci**: The angle of departure (arrival) of the complete root locus at pole (zero) of $G(s)H(s)$ denotes the behaviour of the root loci that pole (zero).

For the RL ($K \geq 0$) these angles can be determined by use of equation.

$$\angle G(s_1)H(s_1) = \sum_{i=1}^Z \angle(s_1 + z_i) - \sum_{j=1}^P \angle(s_1 + p_j)$$

$$= (2q+1)\pi; \quad 0 \leq K < \infty$$

$$\Sigma \angle \theta(z) - \Sigma \angle \theta(p) = (2q+1)\pi$$

For $q = 0, \pm 1, \pm 2, \dots$

Angle of departure/arrival: The root locus leaves from a complex poles and arrives at complex zero. These two angles are known as angle of departure and angle of arrival, respectively. Angle of departure (θ_d) is given by

$$\theta_A = 180^\circ + \arg[G(s)H(s)]$$

where, $G(s)H(s)$ is the angle of $G(s)H(s)$ excluding the poles where the angle is to be calculated.

It is also possible to calculate are $G(s)H(s)$ graphically. Similarly, the angle of arrival is given by

$$\theta_A = 180^\circ - \arg[G(s)H(s)]$$

where, $G(s)H(s)$ is the angle of $G(s)H(s)$ excluding the zero where the angle is to be calculated.

When the angle of the root locus at a pole or zero of $G(s)H(s)$ is determined, the angle of the CRL at the same point differs from this angle by 180° , since equation $(G_1(s)H_1(s)) = 2q\pi$, $-\infty \leq K \leq 0$ must now be used.

Angle of departure from complex pole is given by the $\theta_d = +180 + \angle G'(s)$ where, $G'(s)$ is phase angle of $G'(s)$ counted at complex pole but dropping the contribution of that particular pole. θ_d is measured in the counter clock wise direction from the Horizontal axis (s axis) in the s -plane.

9. **Intersection of RL with Imaginary Axis**: The point where the complete Root Loci intersect the imaginary axis of s -plane, and the corresponding value of K , may be determined by means of Routh Hurwitz criterion. For complex situations with multiple intersections on the imaginary axis, the critical values of K can be more easily determined by finding the phase-crossover points on the Bode plot.

10. **Break Away Point (Saddle Point) on the Complete Root Loci**: Break Away points or saddle points on the root loci of an equation correspond to multiple-order root of the equation.

In general, a breakaway point may involve more than two root loci.

Break Away Point Computed by Analytical Method

The breakaway point on the complex root loci of $1 + KG_1(s)H_1(s) = 0$ must satisfy

$$\frac{dG_1(s)H_1(s)}{ds} = 0 \quad \text{or} \quad \left(\frac{dk}{ds}\right) = 0$$

It is important to point out that the condition for the break away point given by above equation is necessary but not sufficient. In other words, **all break away points must satisfy above equation, but not all solutions of above equation are break away point.** To be a break away point, the solution of above equation must be a factor of characteristic equation for some real K .

11. Calculation of K on RL

Once the root loci have been constructed, the value of K at any point s_i on the loci can be determined by use of the defining equation

$$|K| = \frac{\text{Product of length of vector drawn from poles of } G_1(s)H_1(s) \text{ to } s_i}{\text{Product of length of vector drawn from zeros of } G_1(s)H_1(s) \text{ to } s_i}$$

Some Important Aspect of Root Loci

The analyst or designer may conduct a quick study of the system in the s -plane by making a sketch of the root loci using some or all rules of construction.

Effect of Adding Poles and Zeros to $G(s)H(s)$

1. **Addition of Poles** to $G(s)H(s)$ reduce the relative stability of the closed loop system.

Consider the function

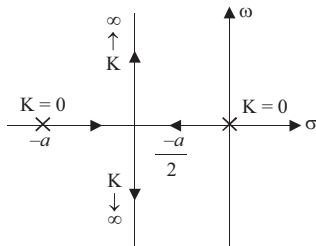


Fig. 9.20 Root loci diagram of $s(s+a) + K = 0$

$$G(s)H(s) = \frac{K}{s(s+a)}; a > 0$$

Characteristic equation $1 + G(s)H(s) = 0$

$$\text{Root locus of } G(s)H(s) = \frac{K}{s(s+a)}$$

Let us introduce a pole at $s = -b$ so that

$$G(s)H(s) = \frac{K}{s(s+a)(s+b)}; b > a$$

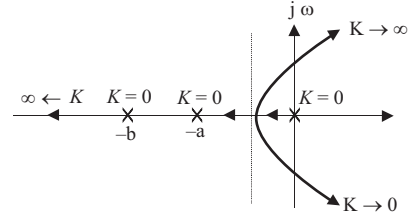


Fig. 9.21 Root Locus diagram for $s(s+a)(s+b) + K = 0$

In general, we may state the adding a pole to the function $G(s)H(s)$ in the left half of s -plane has the effect pushing the original root loci towards the right half of s -plane.

The effects of addition of poles are as follows:

- There is change in shape of the root locus and it shifts towards the imaginary axis.
- The intercept on the $j\omega$ -axis occurs for a lower value of K because of asymptote's angle being lowered down.
- System becomes oscillatory.
- Gain margin and relative stability decreases.
- There is reduction in the range of K .
- A sluggish response can be changed to a quicker response for artful introduction of a pole.
- Settling time increases.

2. **Addition of Zero** to $G(s)H(s)$ has the tendency to stabilize the closed loop system.

Addition of zeros to given function

$$G(s)H(s) = \frac{K}{s(s+a)} \text{ result as}$$

$$G(s)H(s) = \frac{K(s+b)}{s(s+a)}; b > a$$

Its Root locus is as below:

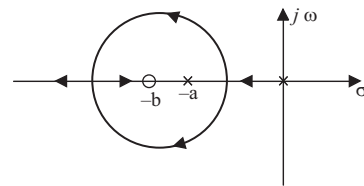


Fig. 9.22

Adding zero to the function of $G(s)H(s)$ has the effect of moving the RL towards the left half.

Result of Addition of Zero

1. All branches of RL now lie completely left half of s -plane, so K can be adjusted to any positive value without causing in stability.
2. By complete RL are now bent toward to LHS of s -plane from $j\omega$ -axis.
3. By suitable adjustment of zero (compensating) along negative axis, the steady state error is within limit.

4. Addition of zero in transfer function causes lag compensation of s -plane. Similar effect will result if a pair of complex-conjugate zero is added to the function.

The effects of addition of zeros are as follows:

- There is change in shape of the root locus and it shift towards the left of the s -plane.
- Stability of the system is enhanced.
- Range of K increases.
- Setting time speeds up.

9.8 POLAR PLOTS

A method of combining the variation of the gain and phase shift with frequency values in a single plot is referred to as the Polar Plot. If we express the frequency response function $G(j\omega)$ in the polar form $Me^{j\phi(\omega)}$ and plot the map of the vector $Me^{j\phi(\omega)}$ in the G -plane as ω varies from zero to infinity, we obtain the “polar plot”. The polar plot is regarded as the mapping of the positive part of the $j\omega$ -axis of the s -plane into a curve in G -plane. *This type of plot is useful in determining the stability of a closed loop system from its open-loop frequency response*, then we study the Nyquist stability criterion.

For a single-loop feedback system, the closed-loop transfer function is written as

$$M(s) = \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

$$M(j\omega) = \left| \frac{G(j\omega)}{1 + G(j\omega)H(j\omega)} \right|$$

$$\begin{aligned} \text{and } \phi(j\omega) &= \angle \frac{G(j\omega)}{1 + G(j\omega)H(j\omega)} \\ &= \angle G(j\omega) - \angle 1 + G(j\omega)H(j\omega) \end{aligned}$$

Procedure to Sketch the Polar Plot of a Given Function

Let $G(s)$ be the given transfer function.

1. Put $s = j\omega$ in the given transfer function $G(s)$ to obtain $G(j\omega)$.
2. Evaluate $|G(j\omega)|$ and $\angle G(j\omega)$.
3. At $\omega = 0$, evaluate $|G(j\omega)|$ and $\angle G(j\omega)$, lowest term of $j\omega$ is taken into consideration.
4. At $\omega = \infty$, evaluate $|G(j\omega)|$ and $\angle G(j\omega)$, highest term of $j\omega$ is taken into consideration.
5. Find intercept of $G(j\omega)$ with real axis and imaginary axis, rationalize $G(j\omega)$.
Put imaginary part equal to zero. Find the value of ω and put this value of ω in real part to get the intersection of $G(j\omega)$ with real axis.
Put real part equal to zero. Find the value of ω and put this value of ω in imaginary part to get the intersection of $G(j\omega)$ with imaginary axis.
6. For $0 < \omega < \infty$, (various values of ω), find their corresponding values of $|G(j\omega)|$ and $\angle G(j\omega)$.

With these values of $|G(j\omega)|$ and $\angle G(j\omega)$ obtained for different values of ω , sketch the polar plot in graph paper.

9.9 NYQUIST PLOT

The frequency-domain analysis of a linear control system is based on the closed-loop transfer function, such as $M(s) = \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}$. In the analysis problem we are

again involved in determining the performance characteristics of the system, and the one of the most important is stability. Thus, we are interested in the location of the characteristic equation roots which are the poles of the closed-loop transfer function.

The Nyquist criterion is a frequency-domain method which is based on *polar plot* and has the following *features* that make it desirable for the analysis as well as the design of control system:

1. It provides the same amount of information on the absolute stability of a control system as does the Routh-Hurwitz criterion.
2. In addition to absolute system stability, the Nyquist criterion indicates the degree of stability of a stable system and gives an indication of how the system stability may be improved, if needed.
3. It gives information on the frequency-domain response of the system.
4. It can be used for a stability study of systems with time delay.
5. It can be modified for non-linear system.

We can formulate the Nyquist criterion by referring to the closed-loop transfer function $M(s) = \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}$ which may represent any linear time-invariant system.

The stability of the system can be studied by investigating the poles of the closed-loop transfer function matrix $M(s)$. For asymptotic stability, all the poles of the transfer function matrix $M(s)$ must be located in the left-half s -plane.

In short, the Nyquist criterion is a graphical method of determining the stability of a closed-loop system by investigating the properties of the frequency-domain plots of $G(s)H(s)$.

Encircled: If point is found to be inside the path, the point is said to be encircled by the closed path. Figure shows that point X is encircled by the closed path where the point Y is not encircled by the closed path.

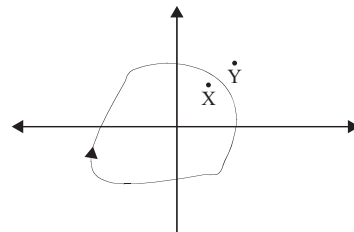
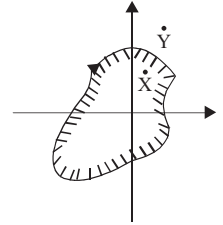
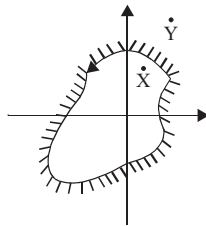


Fig. 9.23 Point X is encircled

Enclosed: If a path is traversed in the clockwise direction and the point is found to lie to the right of the path, the point is said to be enclosed by the path. Figure shows that point X is enclosed by the path, whereas point Y is enclosed by the path in figure.



(a) Point X is enclosed



(b) Point Y is enclosed

Fig. 9.24 Definition of enclosed

Nyquist Stability Criterion

Closed loop stability is checked by below equation:

$$N = (P_+ - Z_+)$$

Where,

N = Number of encirclements of the point $(-1 + j0)$ by $G(s)H(s)$ plot. the positive direction of encirclements being anti-clockwise
 P_+ = Number of poles of $G(s)H(s)$ with positive real part
 Z_+ = Number of zeros of $1 + G(s)H(s) = 0$ with positive real part.

Condition for stability $N = P_+ - Z_+$

For a stable control system $Z_+ = 0$, therefore, the condition for a control system to be stable is

$$N = (P_+ - 0)$$

$$\text{or, } N = P_+$$

For most of the control system $P_+ = 0$, therefore, for such cases the conditions for stability is

$$N = 0$$

Which means that the encirclement of the point $(-1 + j0)$ is nil, i.e., there are no encirclements of the point $(-1 + j0)$ by $G(s)H(s)$ plot or the point $(-1 + j0)$ lies outside $G(s)H(s)$ plot in $G(s)H(s)$ -plane.

A convenient way of determining N with respect to the $(-1 + j0)$ of the $G(s)H(s)$ plane is to draw a line from the point in any

direction to infinity the number of net intersections of this line with $G(s)H(s)$ locus gives the magnitude of N .

Procedure For Drawing of a Nyquist Stability Plot

For the convenience of analysis the Nyquist path is divided into a minimum of three sections:

Step 1: $G(s)H(s)$ plot for $\omega = +0$ to $\omega = +\infty$ i.e., polar plot of a function.

Step 2: $G(s)H(s)$ plot for $\omega = -0$ to $\omega = -\infty$, i.e., mirror image of polar plot of a function.

Step 3: $G(s)H(s)$ plot for $\omega = -0$ to $+0$. It is drawn with radius of infinite magnitude through an angle of $\omega = -\infty$ (clockwise direction) where n is type of system.

Step 4: In most of the cases $\omega = -\infty$ and $\omega = +\infty$ lies at the same point, i.e., origin.

Step 5: Connect all the curves.

Step 6: Note the number of clockwise encirclements about $(-1, 0)$.

Step 7: Decide stability using $N = (P_+ - Z_+)$.

Relative Stability

Nyquist criterion has been for the absolute stability analysis of the system. Using The Nyquist criterion, it is also possible to find the relative stability of the system. By relative stability we mean **now close the system is to instability**, and we can improve the stability of the system. The degree or extent of the system is called relative stability. If the Nyquist polar plot is close to $-1 + j0$ point, the system is on the verge of the instability. The proximity to $-1 + j0$ point is specified in terms of the following two quantities:

1. Gain margin
2. Phase margin

Gain Margin (GM): The gain margin is defined as the reciprocal of open loop transfer function evaluated at the frequency ω_p at which the phase angle is -180° .

$$\text{Gain margin} = \frac{1}{|G(j\omega_p)H(j\omega_p)|}$$

$$\phi = \angle G(j\omega_p)H(j\omega_p) = -180^\circ = -\pi \text{ radian}$$

ω_p = Phase cross over frequency, that is the frequency ω_p at which the polar plot crosses the negative real axis.

Gain margin measures the relative distance between $-1 + j0$ point and the $G(j\omega)H(j\omega)$ plot.

If the phase crossover point A is too near $-1 + j0$ (small GM) will know how much to reduce the gain and if the point A is too far from $-1 + j0$ point (large GM) how much to increase the gain.

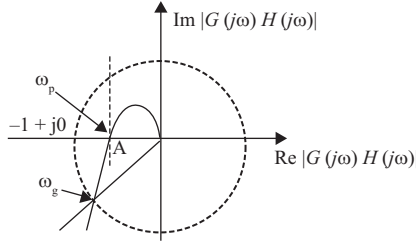


Fig. 9.25

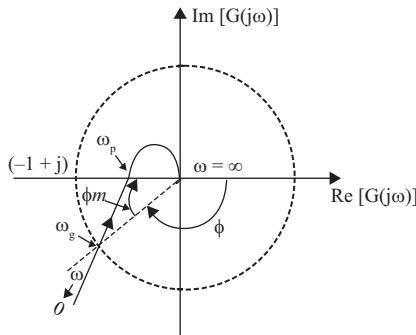
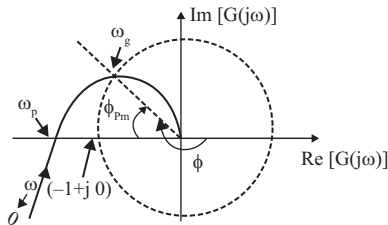
Where, A = Phase crossover point
 ω_p = Phase crossover frequency
 ω_g = Gain crossover frequency

Phase Margin (ϕ_{pm}): It is the angle by which the polar plot is rotated to cause it to pass through $-1 + j0$ point. ϕ_{pm} is the angle between the negative real axis and the radius vector joining the origin to the gain crossover frequency (ω_g). The radius vector is $|G(j\omega)H(j\omega)| = 1$.

The gain cross over frequency ω_g is the frequency at which $|G(j\omega)H(j\omega)| = 1$, that is the point of intersection of polar plot and $(-1, j0)$ circle.

Phase margin $\phi_m = 180^\circ + \phi$

where, $\phi = \angle G(j\omega_g)H(j\omega_g)$ and $|G(j\omega)H(j\omega)| = 1$


 Fig. 9.26 Stable, positive GM and ϕ_m

 Fig. 9.27 Unstable, Negative GM and ϕ_m

In present case, ϕ in the clockwise direction hence negative. So for stability ϕ_{pm} should be positive that is ϕ less than 180° . If ϕ_{pm} is negative, ϕ is greater than 180° , the system is unstable.

Correlation Between Phase Margin and Damping Factor

Consider a unity feedback second-order system with open-loop transfer function

$$G(s)H(s) = \frac{K}{s(\tau s + 1)} = \frac{\omega_n^2}{s(s + 2\delta\omega_n)}$$

where, $\omega_n = \sqrt{K/\tau}$ and $2\delta\omega_n = 1/\tau$

Replacing s by $j\omega$ for obtained the polar plot,

$$\text{we have } G(j\omega)H(j\omega) = \frac{\omega_n^2}{j\omega(j\omega + 2\delta\omega_n)} \quad \dots(1)$$

At the gain crossover frequency $\omega = \omega_1$, the magnitude $|G(j\omega)H(j\omega)| = 1$. Therefore, from Equation (1), we have

$$\frac{\omega_n^2}{\omega_1 \sqrt{(\omega_1^2 + 4\delta^2 \omega_n^2)}} = 1$$

$$\text{or } (\omega_1^2)^2 + 4\delta^2 \omega_n^2 (\omega_1^2) - \omega_n^4 = 0$$

$$\text{which yields } (\omega_1/\omega_n)^2 = (4\delta^4 + 1)^{1/2} - 2\delta^2$$

The *phase margin* of this system is given by

$$\begin{aligned} \phi &= -90^\circ - \tan^{-1} \left(\frac{\omega_1}{2\delta\omega_n} \right) + 180^\circ \\ &= 90^\circ - \tan^{-1} \left[\frac{1}{2\delta} \{ (4\delta^4 + 1)^{1/2} - 2\delta^2 \}^{1/2} \right] \\ &= \tan^{-1} \left[2\delta \left\{ \frac{1}{(4\delta^4 + 1)^{1/2} - 2\delta^2} \right\}^{1/2} \right] \quad \dots(2) \end{aligned}$$

Equation (2) gives a relationship between δ and ϕ for an under damped second-order system.

Linear approximation between ϕ and δ is $\delta = 0.01\phi$ where, ϕ is in degree.

Computation of Gain Margin (GM) and Phase Margin (PM)

GM and PM may be computed by the use of various plots-direct polar plot, inverse plot, Bode plot, log-magnitude versus phase angle plot. In relatively simple cases GM and PM may be computed directly.

Constant-M Circles

Consider any point $G(j\omega) = x + jy$, on the polar plot of $G(j\omega)$. The closed-loop frequency response is

$$T(j\omega) = \frac{C(j\omega)}{R(j\omega)} = \frac{G(j\omega)}{1 + G(j\omega)} = \frac{x + jy}{1 + x + jy} = Me^{j\alpha}$$

$$x_0 = -\frac{M^2}{M^2 - 1} = \frac{M^2}{1 - M^2}$$

$$y_0 = 0$$

and with radius $r_0 = \frac{M}{M - 1}$

1. If M becomes larger and larger as compared to 1, the radius becomes smaller and, ultimately, i.e., $M = \infty$, $x_0 = -1$; $r_0 = 0$ circled converge to the critical point $-1 + j0$.
2. If $M > 1$, the centers are to the left of the point $-1 + j0$.
3. If M becomes smaller and smaller as compared to 1, the radius becomes smaller and ultimately, circles converge to the origin.
4. If $M < 1$, the centers are to the right of the origin, i.e., for $M < 1$, as M decreases, the radii of M -circle reduce monotonically and centers located on positive real and shift toward origin till $M \rightarrow 0$, ($r = 0$ and $x_0 = 0$).
5. If $M = 1$, the locus is of the points which are equidistant from the origin as well as from the $-1 + j0$ point. i.e., $M = 1$; $r_0 = \infty$; $x_0 = \infty$, thus $M = 1$ circle is of infinite radius with center at infinity, i.e., straight line parallel to y -axis intercept on x -axis at $-1/2$.
6. It is observed that $M = 1.3$ circle is tangent to the $G(j\omega)$ plot. Therefore, the maximum value of M is $M = 1.3$, i.e., $M_r = M^2$.

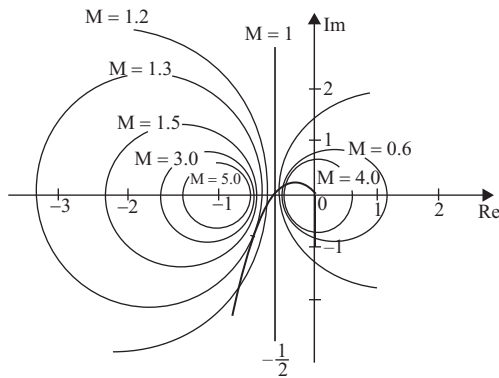


Fig. 9.28 Shows the families of constant M circles

Constant- N Circles

From Equation (1) of 9.9 the phase angle of $T(j\omega)$ is given by

$$\angle T(j\omega) = \alpha = \angle \left(\frac{x + jy}{1 + x + jy} \right)$$

$$\tan \alpha = \frac{y}{x^2 + x + y^2} = N \quad \dots(1)$$

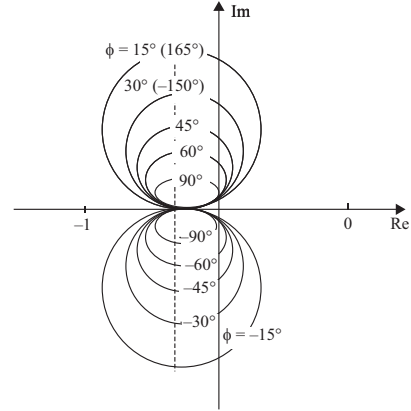


Fig. 9.29 Constant N circles in the polar coordinates

Nichol's Chart

It is possible to obtain the frequency response by plotting the magnitude on dB against the phase angle for various frequencies. The plot obtained is called gain-phase plot or log-magnitude versus phase plot. Below figure shows such a gain-phase plot $G(j\omega) = 1/(1 + \omega T)$, i.e., $G(s) = 1/(1 + sT)$.

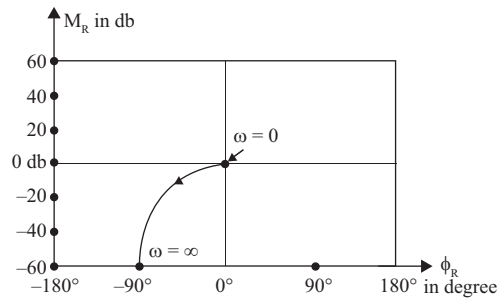


Fig. 9.30

After transferring the constant loci (M circles) and constant phase angle loci (N circles) to the gain phase plot, the resultant chart is known as Nichol's chart.

If we super impose the gain-phase plot of an open-loop transfer function on Nichol's chart, we can get very easily the closed-loop frequency response. The magnitude is expressed in dB, while the phase angle is in degrees. Nichol's chart gives the points of intersection of the gain-phase plot of an open-loop transfer function, which are symmetrical about the -180° internal. The M loci are centered about the critical point (0 dB, -180°).

9.10 BODE PLOT

The Bode plot contains two graphs, one with the magnitude of $G(j\omega)$ plotted in decibels Versus $\log \omega$ or ω and the other with the phase of $G(j\omega)$ in degrees as a function of $\log \omega$ or ω . The Bode plot is also known as the *corner plot* or the *logarithmic plot* of $G(j\omega)$. The name, corner plot, is used since the Bode plot is basically an approximation method in that the magnitude of $G(j\omega)$ in decibels as a function of ω is approximated by straight-line segment.

Characteristics of Bode Plot

Let the open loop transfer function be

$$G(s) = \frac{K(1+T_1s)(1+T_2s)}{s(1+T_as)(1+j2\delta\mu-\mu^2)} \quad \dots(1)$$

where, K , T_1 , T_2 , δ and m are real coefficient. It is assumed that second order polynomial $1+2\delta\mu-\mu^2$, $\mu = \omega/\omega_n$ has two complex conjugate poles.

The magnitude of $G(j\omega)$ in decibels is obtained by multiplying the logarithm to the base 10 of $|G(j\omega)|$ by 20, we have

$$\begin{aligned} |G(j\omega)|_{dB} &= 20 \log_{10} |G(j\omega)| \\ &= 20 \log_{10} |K| + 20 \log_{10} |1+j\omega T_1| + 20 \log_{10} |1+j\omega T_2| \\ &\quad - 20 \log_{10} |j\omega| - 20 \log_{10} |1+j\omega T_a| \\ &\quad - 20 \log_{10} |1+j2\delta\mu-\mu^2| \end{aligned} \quad \dots(2)$$

The phase of $G(j\omega)$ is written

$$\begin{aligned} \angle[G(j\omega)] &= \angle(K) + \angle(1+j\omega T_1) + \angle(1+j\omega T_2) - \\ &\quad \angle(j\omega) - \angle(1+j\omega T_a) - \angle(1+j2\delta\mu-\mu^2) \end{aligned} \quad \dots(3)$$

1. Constant factor: K
2. Poles or zero at the origin: $(j\omega)^{\pm n}$
3. Poles or zero not at $\omega = 0$; $(1+j\omega T)^{\pm n}$
4. Quadratic/complex poles and zero :

$$\left(1 + \frac{2\delta(j\omega)}{\omega_n} - \frac{(j\omega)^2}{\omega_n^2}\right) \text{ or } (1+2\delta\mu-\mu^2)$$

Constant Term K

$$\text{Since } K_{dB} = 20 \log_{10} K = \text{constant} \quad \dots(4)$$

$$\angle K = \begin{cases} 0^\circ & K > 0 \\ 180^\circ & K < 0 \end{cases} \quad \dots(5)$$

Bode plot of the constant factor K is shown on semi-log coordinate.

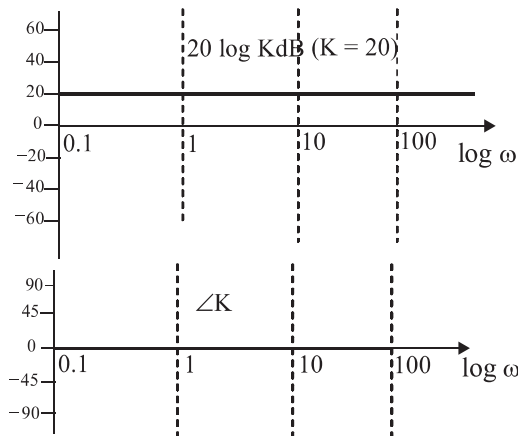


Fig. 9.31 Bode plot of Constant K

Poles and zeros at the origin $(j\omega)^{\pm n}$

Slope (m) = ± 20 n db/decade of frequency

These lines pass through 0 db point at $\omega = 1$.

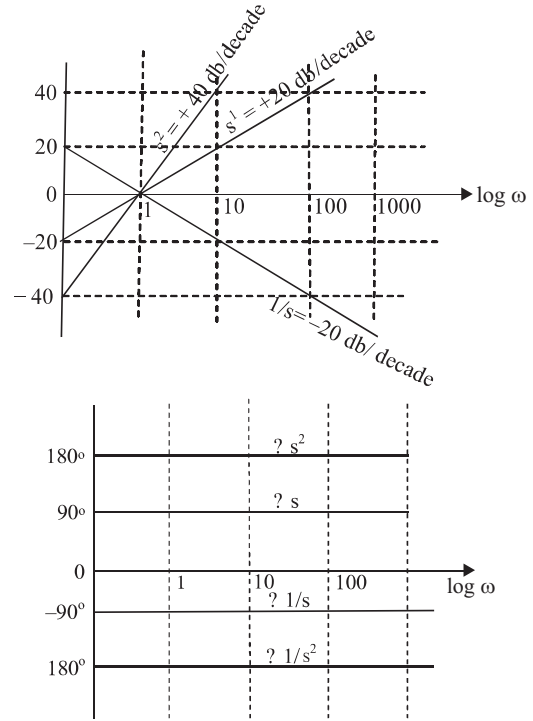


Fig. 9.32 Bode Plot of $(j\omega)^{\pm n}$

The frequencies ω_1 and ω_2 are separated by an *octave* if $\omega_2/\omega_1 = 2$.

Simple Pole and zero $(1+j\omega T)^{\pm 1}$

Let $G(j\omega) = 1 + j\omega T$

Where, T is a real constant. The magnitude of $G(j\omega)$ in decibels is written as,

$$|G(j\omega)|_{dB} = 20 \log_{10} |G(j\omega)| = 20 \log_{10} \sqrt{1 + \omega^2 T^2} \quad \dots(11)$$

$$\phi = \tan^{-1} \omega T \quad \dots(12)$$

To obtain asymptotic approximations of the magnitude of $G(j\omega)$, we consider both very large and very small of ω . At very small frequencies $\omega T \ll 1$. Equation (11) is approximated by

$$\text{At } \omega T \ll 1; \quad |G| \approx 0 \text{ db} \quad \dots(13)$$

$$\text{At } \omega T \gg 1; \quad |G| \approx 20 \log \omega T \quad \dots(14)$$

Equation (14) represents a straight line with slope of +20 db/decade of frequency.

The intersection of this straight line with 0 db axis is found by equating Equation (11) to zero. Which gives

$$20 \log \omega T = 0$$

$$\text{or } \log \omega T = 0 = \log 1$$

$$\omega T = 1$$

$$\text{or } \omega = 1/T \text{ (corner frequency)} \quad \dots(15)$$

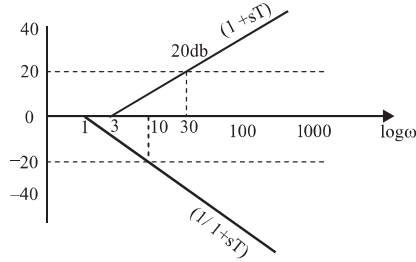


Fig. 9.33 Bode plot magnitude plot for $(1 + sT)$

when $\frac{1}{T} = 3$ and for $(1 + sT)^{-1}$ when $\frac{1}{T} = 1$

Note 1: The error between the actual magnitude curve and the straight line asymptotes is symmetrical with respect to the corner frequency $1/T$. Furthermore, it is useful to remember that the error is 3db at the corner frequency and 1 db at 1 octave above $(2/T)$ and 1 octave below $(0.5/T)$ the corner frequency.

This gives the actual Bode plot.

Note 2: Similar to the magnitude curve, a straight line approximation can be made for the phase curve. Since the phase of $G(j\omega)$ varies from 0° to 90° , we may draw a line 0° at 1 decade below the corner frequency to $+90^\circ$ at 1 decade above the corner frequency.

The maximum deviation of straight line approximation from the actual curve is less than 6° .

Quadratic Poles and Zeros

Consider the 2nd order transfer function:

$$G(s) = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

$$= \frac{1}{\frac{s^2}{\omega_n^2} + \frac{2\delta s}{\omega_n} + 1}$$

$$G(j\omega) = \frac{1}{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2 + j2\delta\left(\frac{\omega}{\omega_n}\right)\right]}$$

Consider the case when $\delta \leq 1$. Since otherwise, $G(s)$ would have two unequal real poles and the Bode plot can be determined by considering $G(s)$ as the product of two transfer function each having a simple poles.

$$|G(j\omega)|_{db} = 20 \log |G(j\omega)|$$

$$= -20 \log \sqrt{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left(\frac{2\delta\omega}{\omega_n}\right)^2}$$

where, ω_n = natural frequency
 ω = operating frequency

Case 1: At very low frequency when, $\omega/\omega_n \ll 1$, at least 0.1 times

$$|G(j\omega)|_{db} = 0 \text{ db} \quad \dots(16)$$

Equation (16) represent a straight line on 0 db axis

Case 2: At very high frequency where, $\omega/\omega_n \gg 1$, i.e., at least 10 times

$$G(j\omega)|_{db} = -20 \log \left(\frac{\omega}{\omega_n}\right)^2 = -40 \log \left(\frac{\omega}{\omega_n}\right) \quad \dots(17)$$

Equation (17) represents straight line with slope of -40 db/decade in plot coordinates.

The intersection of -40 db/decade line with 0 db line is obtained by equating Equation (16) and (17).

$$= -40 \log \left(\frac{\omega}{\omega_n}\right) = 0 \text{ db}$$

$$\text{or, } \frac{\omega}{\omega_n} = 1$$

The frequency $\omega = \omega_n$ is considered as corner frequency of the second order transfer function with the actual $G(j\omega)$ db curve in this case may differ from the asymptotic line because $G(j\omega)$ db and $\angle G(j\omega)$ curve depends on corner frequency ω_n and damping ratio δ .

Phase

$$\angle G(j\omega) = -\tan^{-1} \frac{2\delta\omega/\omega_n}{1 - \left(\frac{\omega}{\omega_n}\right)^2}$$

Magnitude

Case 1: At very low frequency when, $\omega/\omega_n \ll 1$ at least 0.1 time

$$\angle G(j\omega) = 0^\circ$$

Case 2: When, $\omega/\omega_n = 1$, i.e., $\omega = \omega_n$

$$\angle G(j\omega) = -90^\circ$$

Case 3: At very high frequency when, $\omega/\omega_n \gg 1$ at least 10 time

$$\angle G(j\omega) = -180^\circ$$

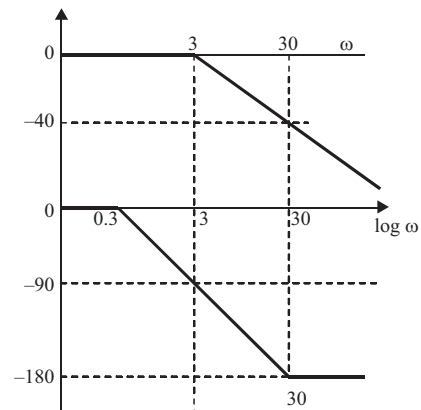


Fig. 9.34 Magnitude and Phase Bode plot for

$$G(s) = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2} \text{ when } \omega_n = 3.$$

Note: For quick solution to $\frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$

If $\delta < 1$, i.e., below 0.8, then

1. Slope will be -40 dB/decade.
2. Angle 0° at 1 decade below the corner frequency and -180° at 1 decade above the corner frequency.
3. Corner frequency = ω_n

Stability Consideration

Gain margin and phase margin give an idea of how far the system is away from the condition of instability. If system

$$G(s) = \frac{K}{s(1 + p_1 s)(1 + p_2 s)}$$

is marginally stable for $K = 90$ and stable for $K < 90$ and $|G(s)H(s)|_{\omega=\omega_p} = 1$.

Where, ω_p is the phase crossover frequency and ω_g is the gain crossover frequency. On the other hand, if the actual gain is less than 90, say $K = 40$, the system will be stable. Gain margin (GM) is defined as the ratio of the critical gain to the actual gain.

$$GM = \frac{\text{Critical value of } K}{\text{Actual value of } K}$$

The phase margin (PM) is defined as

$$PM = 180^\circ + \angle[G(j\omega)H(j\omega)]_{\omega=\omega_g}$$

From the Bode plot one can get gain crossover frequency, phase crossover frequency, gain margin and phase margin.

Phase Margin: To find out phase margin, at first the frequency at which the resultant magnitude is 0 dB is found out. This frequency is called **gain crossover frequency** (ω_g). Now from the phase plot the phase angle (ϕ) is calculated at the phase crossover frequency, the phase margin is given by $PM = 180^\circ + \phi$ as shown in the figure 9.35 below.

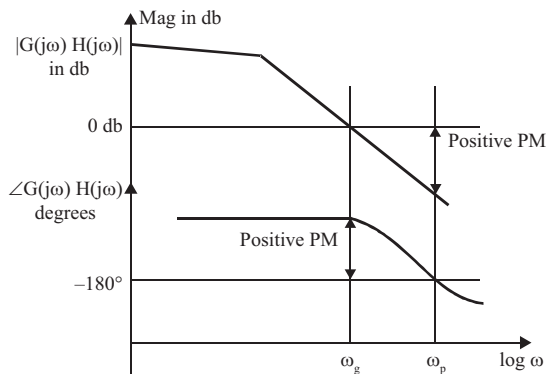


Fig. 9.35 For $\omega_g < \omega_p$ GM and PM positive, stable system

Gain Margin: To find out gain margin, at first the frequency at which the resultant phase curve has a phase of -180° is found out. This frequency is known as **phase crossover frequency** (ω_{pc}). Next the (ω_p) value of the resultant magnitude curve is calculated

at phase crossover frequency. If the value of the resultant curve is below 0 dB, it is considered positive, otherwise it is negative.

For $\omega_g < \omega_p$, both gain margin and phase margin are positive. Therefore, the system is stable as shown in the figure 9.36 below.

For $\omega_g = \omega_p$, the system is marginally stable as shown in figure below.

For $\omega_g > \omega_p$, both gain margin and phase margin are negative and hence the system is unstable as shown in the figure 9.37 below:

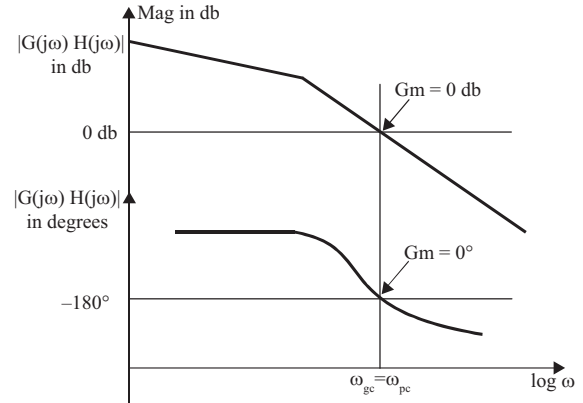


Fig. 9.36 $\omega_g = \omega_p$ marginally stable

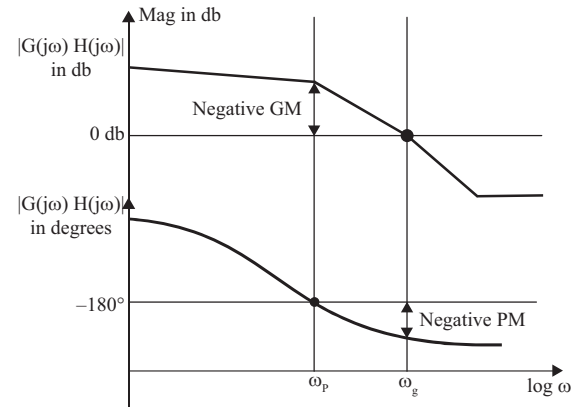


Fig. 9.37 $\omega_p > \omega_g$ GM and PM negative, unstable system

Generally, one takes gain as high as possible so that steady-state error is reduced and acceptable response speed is obtained. Besides these, adequate GM and PM will be maintained when gain is high.

If low gain is considered, GM and PM will be high and this will cause higher steady-state error, higher values of rise time and settling time. Therefore, the system will be sluggish.

Designing a controller is a tremendous task for any control engineer. Generally, a gain margin of 20 dB and phase margin of 30° is taken, which is good enough as a thumb rule.

All-Pass and Minimum-Phase Systems

The cases we have considered so far are termed as minimum-phase transfer functions, i.e., those with all poles and zeros in the left half of the s -plane.

Consider now the special class of transfer function having a pole-zero pattern which is antisymmetric about the imaginary axis, i.e., for every pole in the left half plane, there is a zero in the mirror-image position. A common example of such a transfer function is

$$G_3(j\omega) = \frac{1 - j\omega T}{1 + j\omega T}$$

Whose pole-zero configuration is shown in the figure. It has a magnitude of unity at all frequencies and a phase angle $(-2 \tan^{-1} \omega T)$ which varies from 0° to -180° as ω is increased from 0 to ∞ . The property of unit magnitude at all frequencies applies to all transfer function with ant symmetric pole-zero pattern. Physical system with this property, are called all-pass systems.

Consider next the case where the transfer function has poles in the left half s -plane and zero in both the left and right half s -plane. Poles are not permitted to lie in the right half s -plane because such a system would be unstable. Consider for example the transfer function.

$$G_1(j\omega) = \frac{1 - j\omega T}{(1 + j\omega T_1)(1 + j\omega T_2)}$$

Whose pole-zero pattern is shown in the figure (a). This transfer function may be rewritten as

$$\begin{aligned} G_1(j\omega) &= \left[\frac{(1 + j\omega T)}{(1 + j\omega T_1)(1 + j\omega T_2)} \right] \left[\frac{(1 - j\omega T)}{(1 + j\omega T)} \right] \\ &= G_2(j\omega) G_3(j\omega) \end{aligned}$$

Which now becomes the product of two transfer functions, one $G_2(j\omega)$ having no poles or zero in the right half of s -plane figure. It is evident that $G_1(j\omega)$ and $G_2(j\omega)$ have identical curves of magnitude versus frequency but their phase versus frequency curves are different as shown in the figure with $G_2(j\omega)$ having a smaller range of phase angle than $G_1(j\omega)$. It means that for $G_1(j\omega)$, there is no unique relationship between magnitude and phase, as it is always possible to alter the phase curve without affecting the associated magnitude curve by the addition of an all-pass transfer function. A transfer function which has one or more zeros in the right half s -plane is known as non-minimum phase transfer function.

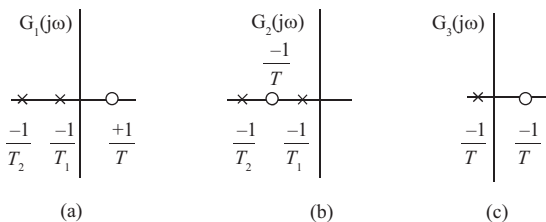


Fig. 9.38 Pole zero plot of (a) Non minimum-phase function (b) Minimum phase function (c) All pass function.

In general, if a transfer function has any zeros in the right half s -plane, it is possible to extract them one by one associating them with all pass transfer function in a manner shown in the

above figure. Each time this is done, the magnitude curve remains unaltered but the phase lag is reduced, until eventually we are left with a function, which contains no zero in the right half s -plane. Such a transfer function has the least (minimum) phase angle range for a given magnitude curve and is called a *minimum-phase function*. It has a unique relationship between its phase and magnitude curves. Typical phase angle characteristics of minimum and non minimum-phase transfer function are shown in below figure. It is seen that the larger the phase lags present in a system, the more complex are its stabilization problems.

Therefore, for control system, elements with non-minimum-phase transfer functions are avoided as far as possible.

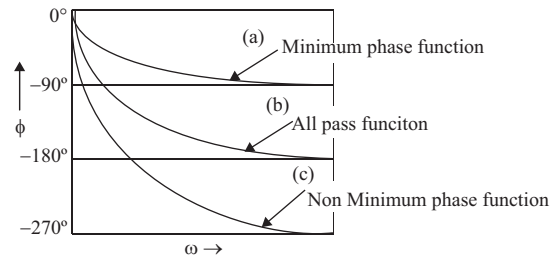


Fig. 9.39 Phase plot of (a) Minimum phase function (b) All pass function (c) Non-minimum-phase function

A common example of a non minimum phase element is transportation lag which has the transfer function.

$$G(j\omega) = e^{-j\omega T} \text{ rad} = 1 \angle -57.3\omega T \text{ deg}$$

The phase angle characteristics where a non-minimum-phase transfer can arise are shown in the below figure.

Other possible situations where a non-minimum phase transfer function can arise are, when more than one possible signal paths are a variable between input and output in addition to a conductive path.

9.11 FREQUENCY DOMAIN SPECIFICATION

Peak Resonance (M_r): This is the maximum value of $M(\omega)$ which indicate the relative stability of the system. Large M_r correspond to a large over shoot in the transient response and optimum value of M_r is usually some where between 1.1 and 1.5.

Resonance Frequency (ω_r): This is the frequency ω_r at which the peak resonance M_r occurs.

Bandwidth: This is defined as the frequency at which the magnitude $M(j\omega)$ drops to 70.7%, i.e., 3 db of its zero frequency level. In general, the bandwidth of a control system indicate the noise filtering characteristic of the system. It gives the measure of the transient response properties:

Large Band width $\rightarrow$ faster rise time

Smaller Band width $\rightarrow$ time response will be slow and system is sluggish.

Cut off Rate: Slope of $\frac{M(\omega)}{\omega}$ at ω_c

- Sharp cut off means noise beyond ω_c are not allowed.
 - S/N ratio improving.
- However in general sharp cut-off characteristic are accompanied by large M_r which means less stable system.
- The maximum overshoot and damped frequency of unit step response in time domain depend upon d only, i.e.,

$$M_p = e^{-\pi\delta/\sqrt{1-\delta^2}};$$

$$\omega_d = \omega_n \sqrt{1-\delta^2}$$

- The resonance peak and resonance frequency of closed loop frequency response M_r depends upon δ i.e.,

$$M_r = \frac{1}{2\delta\sqrt{1-\delta^2}}; \omega_r = \omega_n \sqrt{1-2\delta^2}$$

- Bandwidth is directly proportion to ω_n , i.e.,
- $$\omega_b = BW = \omega_n \left[(1-2\delta^2) + \sqrt{4\delta^4 - 4\delta^2 + 2} \right]^{1/2}$$
- Bandwidth and rise time are inversely proportional to each other, i.e., $t_s = \frac{3}{\delta\omega_n}$ (for 5%)

Higher bandwidth corresponds to larger M_p .

9.12 STATE VARIABLE REPRESENTATION OF LTI CONTROL SYSTEMS

State variable approach, alongwith the output, yields information about the state of the system variable at some predetermined point along the flow of signals.

Its advantages are as follows:

1. It is a direct time domain approach which provides a basis for modern control theory and system optimization.
2. It is very powerful technique for the analysis and design of linear, non-linear, time invariant or time varying multi-input, multi-output system.
3. Easily amenable to solution through digital computers.

Concepts of State, State variables and State Model

State: The state of a dynamic system is the smallest set of variable (called *state variables*) such that the knowledge of these variables at $t = t_0$ together with the input for $t \geq t_0$ completely determines the behaviour of the system for $t > t_0$.

State Variables: The state variables of a dynamic system are the smallest set of variable which determine the state of dynamic system. If at least n variables $x_1(t)$, $x_2(t)$, ... $x_n(t)$ are accessed to completely describe the behaviour of a dynamic system, then such n variables are a set of state variables.

State Vector: If n state variable are necessary to determine the behaviour of a given system, the variable can be considered as n components of vector called *state vector*.

State Space: The n dimensional state variables are elements of n dimensional space called *state space*.

The set of n **state equations** and q **output equations** together form the so called **dynamic equation**.

For ease of expression and manipulation it is convenient to represent the dynamic equation in vector matrix form.

State variable representation given by two equations (1) and (2) and solutions (3) and (4) give two state variables $x(t)$ and $v(t)$ of the system

Matrix Representation of State Equations

Let the n state equations of n th-order dynamic be represented as

$$\frac{dx_i(t)}{dt} = f_i[x_1(t), r_j(t), w_k(t)]$$

$$\frac{dx_i(t)}{dt} = f_i \begin{bmatrix} x_1(t), x_2(t), \dots, x_n(t), r_1(t), r_2(t), \dots, \\ r_p(t), w_1(t), w_2(t), \dots, w_v(t) \end{bmatrix} \quad \dots(1)$$

Where, $i = 1, 2, \dots, n$. The i th state variable is represented by $x_i(t)$, $r_j(t)$ denotes the j th input for $j = 1, 2, \dots, p$, and $w_k(t)$ and $w_v(t)$ denote the k th disturbance input, with $k = 1, 2, \dots, v$.

Let the variable $c_1(t)$, $c_2(t)$, ... $c_q(t)$ be the q output variable of the system. The output variable represents the link between the system and the outside world.

In general, the output variable are functions of the state variable and the input variables. The output equations of a dynamic system can be expressed as

$$c_j(t) = q_j \begin{bmatrix} x_1(t), x_2(t), \dots, x_n(t), r_1(t), r_2(t), \dots, \\ r_p(t), w_1(t), w_2(t), \dots, w_v(t) \end{bmatrix} \quad \dots(2)$$

Where, $j = 1, 2, \dots, q$.

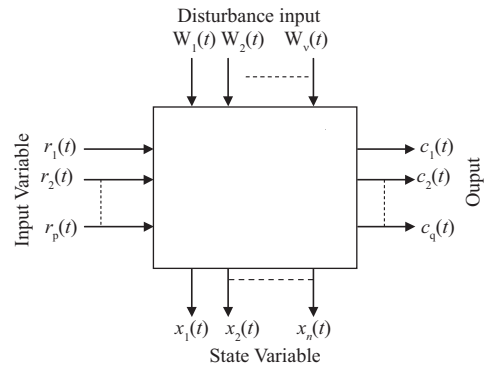


Fig. 9.40 Structure of general control system

The set of n state equations in equations (1) and q output equation in equation (2) together form the so-called *dynamic equation*.

For linear time invariant system, the **dynamic equations** are written as

$$\text{State equation: } [x'(t)] = \frac{dx(t)}{dt} = A x(t) + B(t) + Fw(t)$$

$$\text{Output equation: } [c(t)] = Dx(t) + Er(t) + Hw(t)$$

The combination of state equation and output equations is called as *state model*.

A, B, F, D, E, H are coefficient matrices with constant element.

State Transition Matrix

Once the state equations of linear time invariant system are expressed in the form of equation, i.e.,

$$\frac{dx(t)}{dt} = A x(t) + B r(t) + Fw(t)$$

Where, $Ax(t) \rightarrow$ Homogeneous part

$Br(t)$ and $Fw(t) \rightarrow$ Forcing function part

The next step is to find its solutions.

The **state transition matrix** is defined as a matrix that satisfies the linear homogeneous state equation

$$\frac{d\phi(t)}{dt} = A \phi(t) \quad \dots(1)$$

Let, $\phi(t)$ be an $n \times n$ matrix that represents the state transition matrix, then it must satisfy the equation

$$\frac{d\phi(t)}{dt} = A \phi(t) \quad \dots(2)$$

Further more, let $x(0)$ denote the initial state at $t = 0$, then $\phi(t)$ is also defined by a matrix equation

$$x(t) = \phi(t) x(0) \quad \dots(3)$$

Which is the solution of homogenous state equation at $t \geq 0$.

Computation of State Transition Matrix

Comparing equation (3) and (6)

$$\phi(t) = LT^{-1} [sI - A]^{-1}$$

This is the solution of state equation

$\phi(s) = (sI - A)^{-1}$ is called *resolvent matrix*.

By Classical Method: Here we assume a solution as in the classical method of solving the differential equation

$$\frac{dx(t)}{dt} = A x(t)$$

Let the solution be

$$x(t) = e^{At} x(0^+) \text{ for } t \geq 0$$

where, e^{At} represent a power series of the matrix At and

$$e^{At} = I + At + \frac{1}{2!} A^2 t^2 + \frac{1}{3!} A^3 t^3 + \dots = \sum_{K=0}^{\infty} \frac{A^K t^K}{K!}$$

$$\phi(t) = e^{At}.$$

Properties of STM

1. $\phi(0) = I$ (the identity vector)
2. $\phi^{-1}(t) = \phi(-t)$

3. $\phi(t_2 - t_1) \times \phi(t_1 - t_0) = \phi(t_2 - t_0)$ for any t_0, t_1 and t_2

This property is important since it implies that a straight transition process can be divided into a number of sequential transition, i.e. transition from t_0 to t_2 is equal to the transition from t_0 to t_1 and then t_1 to t_2 .

4. $[\phi(t)]^K = \phi(Kt)$ for any integral K .

State Transition Equation

The state transition equation is defined as the solution of the linear non homogenous state equation.

In general neglect disturbances factor then the linear time invariant state equation

$$\frac{d}{dt} x(t) = Ax(t) + Br(t)$$

$$x(t) = \phi(t - t_0) x(t_0) + \int_{t_0}^t \phi(t - \tau) [Br(\tau) + Fw(\tau)] d\tau$$

Once the state transition equation is determined, the output vector can be expressed as a function of the initial state and the input vector simply by substituting $x(t)$. Thus, the output vector is written

$$c(t) = D \phi(t - t_0) x(t_0) + \int_{t_0}^t D \phi(t - \tau) [Br(\tau) + Fw(\tau)] d\tau + Er(t) + Hw(t)$$

State Space Representation for Electrical Network: The writing of state equation depends on the storage elements i.e., the initial value of the inductor current i_L and capacitor voltage V_c because the state of the system varies from time to time as the energy on the element varies. *There are as many state variable as there are energy storing element.*

Example 1: Write the state equation for series RLC circuit.

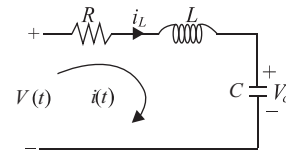


Fig. 9.41

Solution: Corresponding to two storage elements L and C we may choose i_L and V_c as state variable and write dynamic equation by employing KVL and KCL ($i(t) = i_L$)

$$L \frac{di_L}{dt} + Ri(t) + V_c = V(t) \text{ and } C \frac{dV_c}{dt} = i(t)$$

Rearranging by putting chosen state variable on LHS and network variable on RHS of equation.

$$\frac{di_L}{dt} = -\frac{R}{L} i(t) - \frac{1}{L} V_c + \frac{V(t)}{L}$$

$$\frac{dV_c}{dt} = \frac{i(t)}{C}$$

We can rewrite the two equations in matrix form.

$$\begin{pmatrix} \frac{di_L}{dt} \\ \frac{dV_c}{dt} \end{pmatrix} = \begin{pmatrix} \frac{-R}{L} & \frac{-1}{L} \\ \frac{1}{C} & 0 \end{pmatrix} \begin{pmatrix} i_L \\ V_c \end{pmatrix} + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} v(t)$$

Relationship Between Transfer Functions and State Equations

Let a linear time invariant system is described by the dynamic equations. (assume disturbance $\rightarrow 0$)

$$\text{State equation: } \frac{d}{dt}x(t) = Ax(t) + Br(t) \quad \dots(1)$$

$$\text{Output equation: } c(t) = Dx(t) + Er(t) \quad \dots(2)$$

$$G(s) = \frac{C(s)}{R(s)} = D[sI - A]^{-1}B + E \quad \dots(6)$$

Where, $G(s)$ is a $q \times p$ matrix and the existence of $G(s)$ depends on the matrix $[sI - A]^{-1}$ is a non-singular.

The Characteristic Equation, Eigen Values, and Eigen Vectors

The characteristic equation of a linear system can be defined with respect to the system differential equation, transfer function of the state equation.

We know that the characteristic equation is defined as the equation obtained by equating the denominator of the transfer function to zero.

$$G(s) = \frac{C(s)}{R(s)} = \frac{b_{n+1}s^n + b_ns^{n-1} + \dots + b_2s + b_1}{s^n + a_ns^{n-1} + \dots + a_2s + a_1} \quad \dots(1)$$

The characteristic equation of the system is

$$s^n + a_ns^{n-1} + \dots + a_n = 0 \quad \dots(2)$$

interms of state variable we know that transfer function $G(s)$ is given by

$$\begin{aligned} G(s) &= D[sI - A]^{-1}B + E \\ &= D \frac{\text{Adj}(sI - A)}{|(sI - A)|} B + E \\ &= \frac{D \text{Adj}(sI - A) B + (sI - A)E}{|(sI - A)|} \quad \dots(3) \end{aligned}$$

Setting the denominator of the transfer function matrix $G(s)$ to 0, we get characteristic equation as

$$|sI - A| = 0 \quad \dots(4)$$

Eigen Vectors: The $n \times 1$ non-zero vector p_i that satisfies the matrix equation

$$(\lambda_i I - A)p_i = 0$$

Where, λ_i is the i^{th} eigen value of A , is called the *eigenvector* of A associated with the eigen value λ_i .

Concepts of Controllability and Observability

Kalman's Method of Testing Controllability: This method can be applied to any state model (canonical or otherwise) is stated below.

A general n th order multi-input linear time-invariant system (with an m -dimensional control vector)

$$x' = Ax + Bu$$

is completely controllable if and only if the rank of the composite matrix

$$Q_c = [B : AB : A^2B \dots A^{n-1}B] \quad \dots(3)$$

is n . Since only matrices A and B are involved in equation (3), we may say that the pair (AB) is controllable if rank of Q_c is n .

The Kalman's Test of Observability: A general n th order multi-input multi-output linear time-invariant system.

$$\dot{x} = Ax + Bu$$

$$c = Dx + Eu$$

is completely observable if and only if the rank of composite matrix

$$Q_o = [D^T : A^T D^T : (A^T)^2 D^T : \dots : (A^T)^{n-1} D^T] \quad \dots(7)$$

is n . This condition is also referred as the pair (AD) being observable.

Duality Property: Comparing equation (7) with (3), the following observation may be made:

1. The pair (AB) is controllable implies that the pair $(A^T B^T)$ is observable.
2. The pair (AD) is observable implies that the pair $(A^T D^T)$ is controllable.

Thus the concepts of controllability and observability are dual concepts.

State Diagram

This is the extension of signal flow graph to portray state equations and differential equations. The important significance of state diagram is that it forms a close relationship among the state equations, computer simulation and transfer functions.

Important usages of the state diagram:

1. A state diagram can be constructed directly from the state variables and the state equations once the differential equation of the system is given.
2. A state diagram can be constructed from the system's transfer function.
3. This can be used for the programming of the system on an analog computer.
4. This can be used for the simulation of the system on digital computer.
5. The state transition equation in the Laplace Transform domain may be obtained from the state diagram by means of signal flow graph gain formula.

- The transfer function of the system can be obtained from the state diagram.
- The state equations and output equations can be determined from the state diagram.

Example: Consider the following differential equation:

$$\frac{d^2c}{dt^2} + 3\frac{dc}{dt} + 2c = r$$

Obtain its state diagram and analog computer simulation block diagram.

Solution: Equating the highest-ordered term of given equation to the rest to the terms, we have

$$\frac{d^2c}{dt^2} = -2c - 3\frac{dc}{dt} + r \quad \dots(1)$$

Now the variable r , c , $\frac{dc}{dt}$, $\frac{d^2c}{dt^2}$ are represented by node arranged in terms of Laplace transform. These variables are denoted by $R(s)$, $C(s)$, $sC(s)$, $s^2C(s)$ respectively. the node are connected by branches to portray equation (1). Since the variables $sC(s)$ and $C(s)$ are related through integration with respect to time.

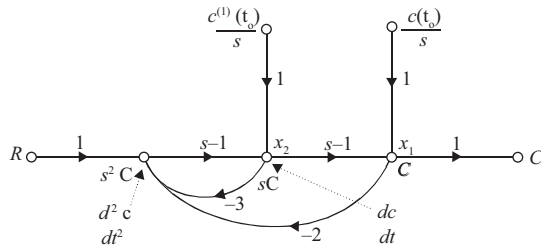


Fig. 9.42 State diagram for given equation

Following the procedure as outlined, the state diagram of the system is shown in the above figure

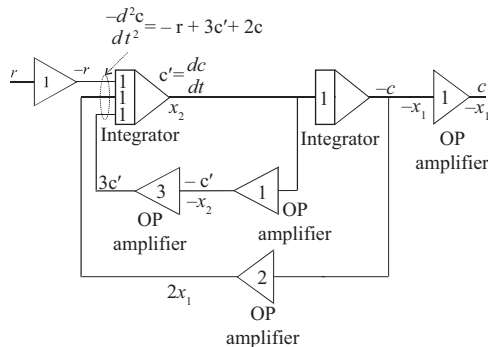


Fig. 9.43 Analog-computer block diagram for the system described by given equation

Decomposition of Transfer Functions

There are various methods of characterizing a linear system. It is useful to summarize briefly and gather thought at this point.

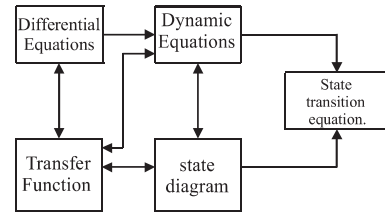


Fig. 9.44 Block diagram showing the relationships among various methods of describing linear systems

Above figure shows that the starting point of the description a linear system may be the system's differential equation, transfer function, or dynamic equations. It is demonstrated that all these methods are closely related. The state diagram is useful tool which not only can lead to the solutions of the state equations but also serves as a vehicle of translation from one type of description to the others. A block diagram is drawn as shown in the above figure to illustrate the interrelationships between the various loops describing a linear system. The block diagram shows that starting, for instance, with the differential equation of a system, one can get to the solution by use of the transfer function method or the state equation method. The block diagram also shows that the majority of the relationships are bilateral, so a great deal of flexibility exists between the methods.

The process of going from the transfer function to the state diagram or the state equations is called the decomposition of the transfer function. In general, there are three basic ways of decomposing a transfer function: direct decomposition, cascade decomposition, and parallel decomposition. Each of these three schemes of decomposition has its own advantages and is best suited for a particular situation.

$$C(s) = a_2x_1 + a_1x_2 + \frac{a_0}{b_0}R(s)$$

9.13 CONTROL SYSTEM COMPENSATOR

Phase-Lead Controller/Compensator

The phase-lead controller is used for the compensation of control systems, and the design is carried out in the time domain or the s -plans via the root loci. In this section the phase-lead controller is to be designed using frequency domain techniques.

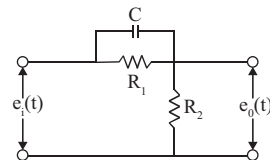


Fig. 9.45 Phase lead network

The transfer of the network is derived as follows by assuming that the source impedance which the lead network sees is zero, and the output load impedance is infinite. This assumption

is necessary in the derivation of the transfer function of any four terminal network.

$$\frac{E_2(s)}{E_1(s)} = \frac{R_2 + R_1 R_2 C s}{R_1 + R_2 + R_1 R_2 C s} \quad \dots(1)$$

or

$$\frac{E_2(s)}{E_1(s)} = \frac{R_2}{R_1 + R_2} \cdot \frac{1 + R_1 C s}{\frac{R_1 R_2}{R_1 + R_2} C s} \quad \dots(2)$$

Let

$$a = \frac{R_2}{R_1 + R_2} a > 1$$

and

$$T = \frac{R_1 R_2}{R_1 + R_2} C$$

Then equation (3) becomes

$$\frac{E_2(s)}{E_1(s)} = \frac{s + 1/aT}{s + 1/T} a > 1 \quad \dots(3)$$

As seen from equation (3), the transfer function of the phase-lead network has a real zero at $s = -1/aT$ and a real pole at $s = -1/T$. These are represented in the s -plane as shown in the figure below. By varying the value of a and T , the pole and zero may be located at any point on the negative real axis in the s -plane. Since $a > 1$, the zero is always located to the right of the pole, and the distance between them is determined by the constant a .

“The zero being to the right of the pole is the reason that the phase-lead controller can improve the relative and absolute stability of a closed-loop control system”.

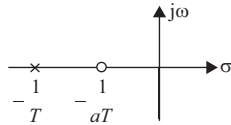


Fig. 9.46 Pole zero configuration of phase-lead (HPF) network

$$\frac{E_2(s)}{E_1(s)} = \frac{\left(s + \frac{1}{aT}\right)}{\left(s + \frac{1}{T}\right)}$$

or

$$\sin \phi_m = \frac{a - 1}{a + 1} \quad (7)$$

This last expression is a very useful relationship in the proper selection of the value of a for compensation design.

Phase-Lag Controller

We demonstrated that the phase-lag controller generally has a wider range of effectiveness than the phase-lead controller.

Figure below shows a simple RC network that realizes the transfer function of equation (1). If we assume that the input impedance of the network is zero and the output impedance that network sees is infinite, the transfer function of the network is written

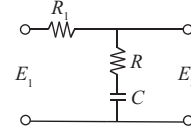


Fig. 9.47 RC phase lag network (LPF)

$$\frac{E_2(s)}{E_1(s)} = \frac{1 + R_2 C s}{1 + (R_1 + R_2) C s} \quad \dots(1)$$

$$= \frac{1 + \frac{R_2}{(R_1 + R_2)} \cdot (R_1 + R_2) C s}{1 + (R_1 + R_2) C s}$$

where,

$$= \frac{R_2}{R_1 + R_2} a < 1$$

$$T = (R_1 + R_2) C.$$

The transfer function of the phase-lag controller given in equation below:

$$\frac{E_2(s)}{E_1(s)} = \frac{1 + aTs}{1 + Ts} a < 1 \quad \dots(2)$$

In the present case the zero-frequency gain of the transfer function of equation (2) is unity, but at infinite frequency there is an attenuation of a ($a < 1$).

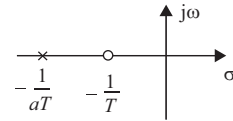


Fig. 9.48 Pole zero configuration of $\frac{1 + aTs}{1 + Ts}$; $a < 1$ of phase lag network

The transfer function of the phase-lag controller in equation (2) has a real zero at $s = -1/aT$ and a real pole at $s = -1/T$. Since a is less than unity, the pole is always located to the right of the zero, and the distance between them is determined by a .

$$\sin \phi_m = \frac{a - 1}{a + 1}$$

Phase Lag-Lead Controller

The lag-lead (or lead-lag) controller can also be designed using the frequency-domain methods. When designed properly, lag-lead compensation combines the advantages of the phase-lead controller and phase-lag controller.

The transfer function of a simple lag-lead (or lead-lag) controller can be written

$$G_c(s) = \left(\frac{1 + aT_1 s}{1 + T_1 s} \right) \left(\frac{1 + bT_2 s}{1 + T_2 s} \right) \quad \dots(1)$$

|← lead →| ← lag →|

where, $a > 1$ and $b < 1$, and the attenuation factor ($1/a$) of the phase-lead controller is not included in the equation if we assume that adequate loop gain is available in the system to compensate for this loss.

Usually it is not necessary to cascade the lead and the lag network of figures for the realization of equation (1) if a and b need not be specified independently. A network that has lag-lead characteristics, but with fewer number of elements, is shown in the figure below:

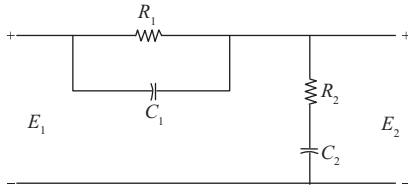


Fig. 9.49 Lag-lead network

The transfer function of the network is

$$G_c(s) = \frac{E_2(s)}{E_1(s)} = \frac{(1 + R_1 C_1 s)(1 + R_2 C_2 s)}{1 + (R_1 C_1 s + R_1 C_2 + R_2 C_2)s + R_1 R_2 C_1 C_2 s^2}$$

Comparing equation (1) with equation (2), we have

$$aT_1 = R_1 C_1$$

$$bT_2 = R_2 C_2$$

$$T_1 T_2 = R_1 R_2 C_1 C_2$$

$$abT_1 T_2 = R_1 R_2 C_1 C_2$$

thus $ab = 1$

Which means that a and b cannot be specified independently

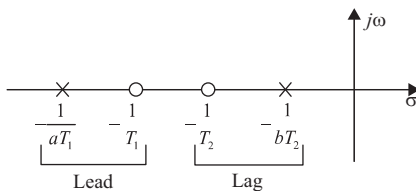


Fig. 9.50 Pole-zero configuration of $G_c(s) = \left(\frac{1 + aT_1 s}{1 + T_1 s} \right) \left(\frac{1 + bT_2 s}{1 + T_2 s} \right)$

9.14 CONTROLLING SYSTEM/CONTROLLERS

The time domain characteristics of control system are represented by the transient and steady state response of system when certain test signal is applied. For a step function input, the peak overshoot, rise time and settling time are often used to measure the performance of the system. The damping ratio and the natural undamped frequency may be used to indicate the relative stability of the system.

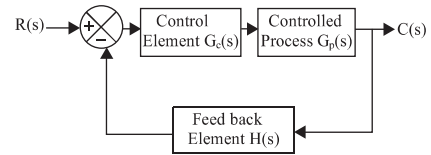


Fig. 9.51 Controller configuration on control system compensation

An automatic control system is used to maintain its output within desirable limit by means of control action. Any deviation of the output from the reference input is detected by the error detector. This error is used as actuating signal for control action through the controller. Various control actions are used for improving transient and steady state response of control system.

Proportional Control Action

There is a continuous linear relationship between the output and the input of the control element.

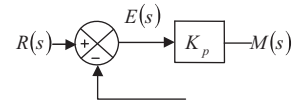


Fig. 9.52 Proportional Controller

$$m(t) = K_p e(t) \Rightarrow \frac{M(s)}{E(s)} = K_p$$

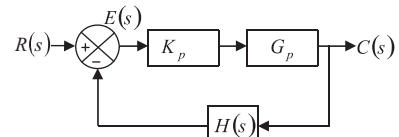


Fig. 9.53 Proportion controller with control system

$$E_{ss} = \lim_{s \rightarrow 0} \frac{S R(s)}{1 + K_p G_p(s) H(s)}$$

- Increase in forward path gain reduces the steady state error.
- It has very simple implementation.
- If forward path gain is increased then *system is made faster*, steady state error reduces but maximum overshoot, i.e., offset is increased.
- By proper choice of forward path gain, adjustments can be made between maximum overshoot and steady state error.

Derivative Control Action

In this, the control action the output is proportional to the time rate of change of input.

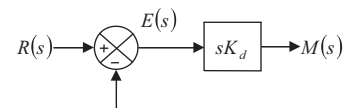


Fig. 9.54 Derivative Controller

$$m(t) = K_d \frac{de(t)}{dt} \Rightarrow \frac{M(s)}{E(s)} = sK_d$$

- Damping increases and settling time decreases.

Integral Control Action

In this control action the output is proportional to time integral of the input.

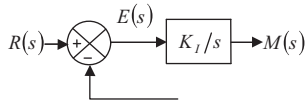


Fig. 9.55 Integral controller

$$m(t) = K_I \int e(t) dt$$

$$\frac{M(s)}{E(s)} = \frac{K_I}{s}$$

- Highly steady state accurate.

Proportional Plus Derivative Controller (PD)/ Derivative Error Compensation

A system is said to possess **derivative error compensation** when the generation of its output depends in some way on the rate of change of actuating signal.

This type of compensation is easily introduced by using a controller containing two term, one proportional to the derivative of the actuating signal and the other proportional to the actuating signal itself. This is also known as *PD-controller*.

The output of the controlling system is proportional to a linear rate change

$$\frac{M(s)}{E(s)} = (1 + s\tau_d)$$

where, τ_d = delay time

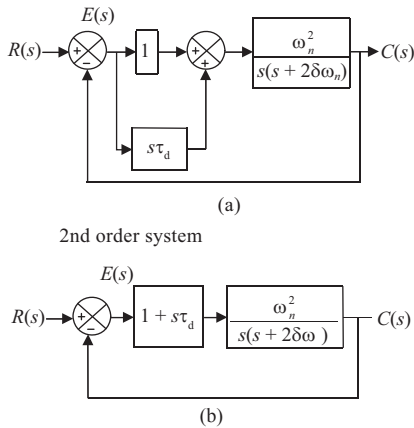


Fig. 9.56 (a) and (b) are block diagram of 2nd order system with PD Controller

$$\frac{C(s)}{E(s) + E(s)s\tau_d} = \frac{\omega_n^2}{s(s + 2\delta\omega_n)}$$

$$\frac{C(s)}{E(s)} = \frac{(1 + s\tau_d)\omega_n^2}{s(s + 2\delta\omega_n)} = G(s)$$

$$\frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)} = \frac{(1 + s\tau_d)\omega_n^2}{s^2 + (2\delta\omega_n + \tau_d\omega_n^2)s + \omega_n^2}$$

By *PD* controller one zero gets added up in the transfer function.

Characteristic equation of new system

$$s^2 + (2\delta\omega_n + \tau_d\omega_n^2)s + \omega_n^2$$

1. SSE $\left(\frac{1}{K_v} = \text{fixed}\right)$ is not affected.

2. It increases damping ratio $\left(\delta' = \left(\delta + \frac{K_D\omega_n}{2}\right)\right)$.

3. It decreases overshoot $\left(K_v = \frac{K_p\omega_n}{2\delta}\right)$.

4. Rise time and settling time are reduced.

5. It is a high pass filter.

- $G_c(s) = (K_p + K_D \cdot s)$

- With derivative compensation, natural frequency remains same, but δ (damping factor) gets increased.

- t_s (settling time) = $4/\delta\omega_n$ as δ increases, t_s gets reduced so system becomes fast.

Proportional Plus Integral/Integral Error Compensation

In this scheme, the output response depends in some manner upon the integral of the actuating signal. This type of compensation is introduced by using a controller which produces an output signal consisting of two terms, one proportional to the actuating signal and the other proportional to its integral. This is known as proportional plus integral controller (**PI controller**).

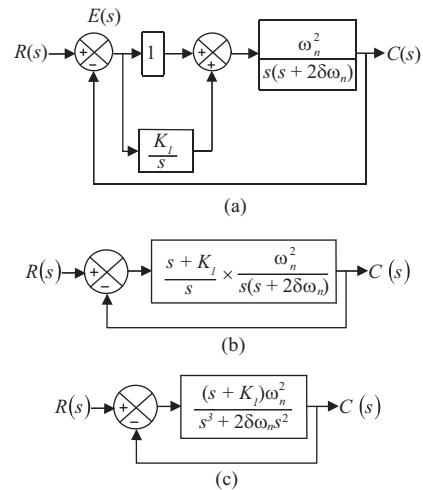


Fig. 9.57 (a), (b) and (c) are block diagram of PI controller

Closed loop Transfer function

$$\frac{C(s)}{R(s)} = \frac{(s + K_I)\omega_n^2}{s^2 + 2\delta\omega_n s^2 + \omega_n^2 s + K_I\omega_n^2} = G(s)$$

$$R(s) = \frac{R(s)}{1 + G(s)}$$

$$E(s) = \frac{s^2(s + 2\delta\omega_n) \cdot R(s)}{s^3 + (s^2 2\delta\omega_n + \omega_n^2(s + K_I))} = G(s)$$

$$e_{ss} = \lim_{s \rightarrow 0} s \cdot E(s)$$

$$= \lim_{s \rightarrow 0} \frac{s \cdot s^2(s + 2\delta\omega_n) \cdot R(s)}{[s^2(s + 2\delta\omega_n) + \omega_n^2(s + K_I)]}$$

Case 1: $R(s)$ = Step function = $1/s$

$$e_{ss} = 0$$

Case 2: $R(s)$ = Ramp /velocity function = $1/s^2$

$$e_{ss} = 0$$

Case 3: Accelerating function

$$e_{ss} = \text{some constant}$$

1. Steady state error can be reduced by incorporating integral control.
2. The order of the system increases and higher order system are more likely to be unstable.
3. It is low pass filter. Noise is filtered out.
 - In this system, we have two blocks one is proportional and other is integral block.
 - Integral error compensation changes a second order system into a third-order, i.e., Type 1 system to Type 2 system.
 - Improvement of damping and reduction of over shoot
 - Bandwidth also increases.
 - This eliminates error constant so we can use this to meet high accuracy requirement.
 - As the order of system get increased, this introduces a distinct possibility of system instability.

Proportional + Integral + Derivative (PID) Controller

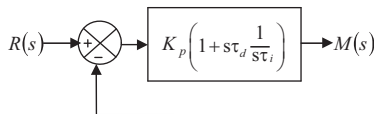


Fig. 9.58 PID Controller

$$G(s) = K_p + K_d s + \frac{K_I}{s}$$

It combines all the advantages of proportional derivative and integral control action. It is BPF or BPF depends upon controller parametre.

That the steady-state error for velocity input is zero and also the steady-state error caused by disturbance torque (assumed to

be step) is zero. These facts are easily established directly from the inclusion of the integral term in the controller.

Effect on dynamic response of the system caused by a PID controller is not obvious as the characteristic equation becomes of third order. Inclusions of two zeros in the numerator ($K_D s^2 + K_P s + K_I$) helps in the system acquiring desirably dynamic qualities but the third-order characteristic equation causes the system to become unstable for certain combination of gains (K_v, K_p, K_D, K_I).

Derivative (Rate) Feedback Control/Derivative Output Compensation

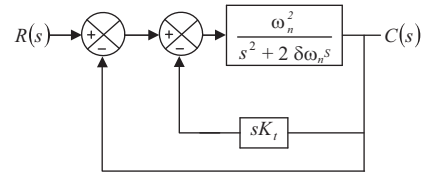


Fig. 9.59 Block diagram of derivative output compensation

$$\frac{C(s)}{E(s)} = \frac{\omega_n^2/s(s + 2\delta\omega_n)}{1 + \frac{\omega_n^2(sK_I)}{s(s + 2\delta\omega_n)}}$$

$$= \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + K_I \omega_n^2} = G(s)$$

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + (2\delta\omega_n + K_I \omega_n^2)s + \omega_n^2}$$

Characteristic equation

$$s^2 + (2\delta\omega_n + K_I \omega_n^2)s + \omega_n^2 = 0$$

$$\text{If } R(s) = \frac{1}{s^2}$$

$$e_{ss} = \frac{\omega_n K_I + 2\delta}{\omega_n}$$

1. Steady state error is increased by incorporating feedback control.
2. Actual damping with feedback control is increased which decreases the overshoot.
3. Compensation with this increase both system damping and natural frequency resulting in reduced settling time, i.e.,

$$\omega_n \uparrow \Rightarrow t_s \downarrow \text{ as } t_s = \frac{4}{\delta\omega_n}.$$

QUESTION BANK

LEVEL 1

1. Root Loci starts from
 - (a) poles and ends on zeros
 - (b) zeros and ends on poles
 - (c) zeros and ends on infinity
 - (d) poles and ends on infinity
2. A unit impulse functions on differentiation result in
 - (a) unit doublet
 - (b) unit triplet
 - (c) unit parabolic function
 - (d) unit ramp function
3. The effect of adding poles and zero can be determined quickly by
 - (a) nicholas chart
 - (b) nyquist plot
 - (c) bode plot
 - (d) root locus
4. Magnetic amplifier are used for
 - (a) voltage amplification
 - (b) power amplification
 - (c) current amplification
 - (d) frequency amplification
5. In the derivative for error compensation
 - (a) damping decreases and settling time decreases
 - (b) damping increases and setting time increases
 - (c) damping decreases and setting time increases
 - (d) damping increases and setting time decreases
6. When all the roots of the characteristic equation are found in the left half of s plane, the system response due to install condition will
 - (a) increase to infinity as time approaches infinity
 - (b) decreases to zero as time approaches infinity
 - (c) remain constant for all time
 - (d) be oscillating
7. A stepper motor
 - (a) is a two phase induction motor
 - (b) is a kind of rotating amplifier
 - (c) is an elect romantic transducer commonly used to convert an angular position of a shaft into an electrical system
 - (d) is an electromechanical device which-actuates a train of step angular (or linear) movements in response to a train of input pulses on one to one basis
8. In the type 1 system, the velocity log error is
 - (a) inversely proportional to bandwidth of the system
 - (b) directly proportional to gain constant
 - (c) inversely proportional or gain constant
 - (d) independent of gain constant
9. Dither phenomenon can be used to overcome the
 - (a) large steady state error
 - (b) columbic frication
 - (c) instability of a system
 - (d) viscous friction
10. The ac motor used in servo applications is a
 - (a) single-phase induction motor
 - (b) two-phase induction motor
 - (c) three-phase inductor motor
 - (d) synchronous motor
11. In position control system, the device used for providing rate-feedback voltage is called
 - (a) potentiometre
 - (b) synchro transmitter
 - (c) synchro transformer
 - (d) technogenerator
12. The purpose of the series Quadrature windings in a amplisdyne is to
 - (a) neutralize the effect of armature reaction
 - (b) reduce commutation difficulties
 - (c) increase the gain
 - (d) increase the response time
13. Which one of the following is an example of open loop system?
 - (a) a windscreen wiper
 - (b) aqualung
 - (c) respiratory system of an animal
 - (d) a system for controlling anti-rocket missiles
14. An electronic chemical device which actuates a train of step angular movements in response to a train of input pulses on one to one basis is
 - (a) synchro control transformer
 - (b) LVDT
 - (c) stepper motor
 - (d) AC tachogenerator
15. Which one of the following transducers is used to obtain the output position in a position control system?
 - (a) strain Gauge
 - (b) load cell
 - (c) synchro
 - (d) thermistor
16. Which one of the following is the best controller, to use for an electrically heated temperature-controlled liquid heater?
 - (a) two position controller
 - (b) proportional position controller
 - (c) floating controller
 - (d) single position controller
17. When phase-lag compensation is used in a system gain cross-over frequency, bandwidth and undamped frequency are respectively
 - (a) increased, increased increased
 - (b) increased, increased, decreased
 - (c) increased, decreased, decreased
 - (d) decreased, decreased, decreased

18. The root locus of a system has four separate loci. The system can have
 (a) Four poles and four zeros
 (b) Four poles or four zeros
 (c) Six poles and two zeros
 (d) Two poles and two zeros
19. Which one of the following is open loop?
 (a) The respiratory system of man
 (b) A system for controlling the movement of the slide of a copying milling machine
 (c) A thermostatic control
 (d) Traffic light control
20. The polar plot of a transfer function with ω as the parametre is known as the
 (a) Nyquist plot (b) Bode plot
 (c) Root-locus (d) Signal flow graph
21. The steady state error due to a ramp input for a type-2 system is equal to
 (a) zero (b) infinite
 (c) non-zero number (d) constant
22. A synchro transmitter consists of a
 (a) Salient pole rotor winding excited by an ac supply and a three-phase balanced stator winding
 (b) Three-phase balanced stator winding excited by a three-phase balanced ac signal and rotor connected to a dc voltage source
 (c) Salient pole rotor winding excited by a dc signal
 (d) Cylindrical rotor winding and a stepped stator excited by pulses
23. The torque-speed characteristic of two-phase induction motor is largely affected by
 (a) voltage (b) $\frac{R}{X}$ and speed
 (c) $\frac{X}{R}$ (d) supply voltage frequency
24. Which of the following are the characteristics of closed-loop system?
 1. It does not compensate for disturbances
 2. It reduces the sensitivity of plant-parametre variations
 3. It does not involve output measurements
 4. It has the ability to control the system transient response
 Select the correct answer using the codes given below:
 (a) 1 and 4 (b) 2 and 4
 (c) 1 and 3 (d) 2 and 3
25. If a ramp input is applied to Type-2 system the steady-state error is
 (a) positive constant (b) negative constant
 (c) zero (d) positive infinity
26. A transfer function of control system does not have pole zero cancellation. Which one of the following statements is true?
 (a) System is neither controllable nor observable
 (b) System is completely controllable and observable
 (c) System is observable but uncontrollable
 (d) System is controllable but unobservable
27. Which one of following statements is incorrect with reference to pneumatic system?
 (a) Operating pressure is low compared to hydraulic system
 (b) Leaks can create problems as well as fire hazards
 (c) They are insensitive to temperature change
 (d) High compressibility of air results in longer time delays
28. Consider the following statements regarding AC servo motor
 1. The torque-speed curve has negative slope
 2. It is sensitive to noise
 3. The rotor has high resistance and low inertia
 4. It has slow acceleration
 Which of the following are the characteristics of AC servomotor as control component?
 (a) 1 and 2 (b) 2 and 3
 (c) 1 and 3 (d) 2 and 4
29. Backlash in a stable control system may cause
 (a) underdamping (b) overdamping
 (c) high level oscillations (d) low level oscillations
30. Consider the following statements:
 1. If the input is sine wave of radian frequency ω , the output in general is non-sinusoidal containing frequencies which are multiple of ω
 2. The jump resonance may occur
 3. The system exhibits self-sustained oscillation of fixed frequency and amplitude
 4. The response to a particular test signal is a guide to the behaviour to other inputs
 Which of the above statements are correct and peculiar to non-linear system?
 (a) 1, 3 and 4 (b) 2, 3 and 4
 (c) 1, 2 and 3 (d) 1, 2 and 4
31. The output of first order hold between two consecutive sampling instants is a
 (a) constant (b) quadratic function
 (c) ramp function (d) exponential function
32. A property of phase-lead compensation is that the
 (a) Overshoot is increased
 (b) Bandwidth of closed loop system is reduced
 (c) Rise-time of closed loop system is reduced
 (d) Gain margin is reduced
33. Which one of the following methods is not used for the analysis of nonlinear control systems
 (a) Phase plane method (b) Describing function method
 (c) Liapunov's method (d) Piecewise linear method
34. Which one of the following effects in the system is not caused by negative feedback?
 (a) Reduction in gain
 (b) Increases in bandwidth
 (c) Increases in distortion
 (d) Reduction in output impedance

35. Consider the following statements regarding advantages of using the generalized error coefficients
- The generalised error coefficients provide a simple way of determining the nature of the response of a feedback control system to almost any arbitrary input
 - The generalized error coefficients lead to the calculation of the steady-state response without actually solving the system differential equation
 - The generalized error coefficients establish relationships among the various types of inputs
- Which of the above statements are correct?
- 1, 2 and 3
 - 1 and 2
 - 2 and 3
 - 1 and 3
36. Which one of the following is not a correct reason to select feedback compensation over cascaded one?
- No amplification is required as the energy transfer is from higher to lower level
 - Suitable devices are not available for compensation (series)
 - It is economical
 - Provides greater stiffness against load disturbances
37. Consider the following statements:
- Servomotor have lighter rotor as compared to ordinary motors and hence lower inertia
 - Back e.m.f in field controlled dc motors acts as minor loop feed back and results in increased damping and improved transient response
 - Permanent magnet dc servo motors can be used in either armature controlled or field-controlled modes
- Which of the above statements are not correct?
- 1 and 2
 - 2 and 3
 - 1 and 3
 - 1, 2 and 3
38. Consider the following statements:
- A first order system with a proportional controller exhibits an offset to a step input. In order to reduce the offset. It is necessary to
- Increase the gain proportional controller
 - Add a derivative mode
 - Add an integral mode
- Select the correct answer using the code given below:
- 1, 2 and 3
 - 1 and 2
 - 2 and 3
 - 1 and 3
39. In a speed control systems, output rate feedback is used to
- Limit the speed motor to
 - Limit the acceleration of the motor
 - Reduce the damping of the system
 - Increase the gain margin
40. For a discrete-time system to be stable, all the poles of the Z transfer function should lie
- Within a circle of unit radius
 - Outside the circle of unit radius
 - On left half of Z plane
 - On right half of Z – plane
41. Signal flow graph is used to find
- Stability of the system
 - Controllability of the system
 - Transfer function of the system
 - Poles of the system
42. The final value theorem is used to find the
- Steady state value of the system output
 - Initial value of the system output
 - Transient behavior of the system output
 - None of these
43. The transfer function of a linear system is the
- Ratio of the output, $v_o(t)$, and input, $v_i(t)$
 - Ratio of the derivative of the output and the input
 - Ratio of the Laplace transform of the output and that of the input with all initial conditions zeros
 - None of these
44. Non-minimum phase transfer function is defined as the transfer function
- Which has zeros in the right-half S-plane
 - Which has zeros only in the left-half S-plane
 - Which has poles in the right-half S-plane
 - Which has poles in the left-half S-plan.
45. If the open-loop transfer function is a ratio of a numerator polynomial of degree 'm' and a denominator polynomial of degree 'n' then the integer (n-m) represents the number of
- breakaway points
 - unstable les
 - separate root loci
 - asymtotes
46. Despite the presence of negative feedback, control systems still have problems of instability because the
- Components used have non-linerarities
 - Dynamic equations of the subsystem are not known exactly
 - Mathematical analysis involves approximations
 - System has large negative phase angle at high frequencies
47. In a LVDT, the two secondary voltages
- Are independent of the core position
 - Vary unequally depending on the core position
 - Vary equally depending on the core position
 - Are always in the phase Quadrature
48. A differentiator has transfer function whose
- Phase increases linearly with frequency
 - Amplitude remains constant
 - Amplitude increases linearly with frequency
 - Amplitude decreases linearly with frequency
49. Introduction of integral action in the forward path of a unity feedback system results in a
- Marginally stable system
 - System with no steady state error
 - System with increased stability margin
 - System with better speed o response

50. None of the poles of linear control system lie in the right half of s-plane. For a bounded input, the output of this system
 (a) Is always bounded (b) Could be unbounded
 (c) Always tends to zero (d) None of the above
51. The phase lead compensation is used to
 (a) Increases rise time and decrease overshoot
 (b) Decreases both rise time and overshoot
 (c) Increases both rise time and overshoot
 (d) Decreases rise time and increases overshoot
52. A set of linear equations is represented by the matrix equation. $Ax = b$. The necessary condition for the existence of a solution for this system is
 (a) A must be invertible
 (b) b must be linearly depended on the columns of A
 (c) b must be linearly independent of the columns of A
 (d) none of the above
53. Ratio of the rotor reactance X to the rotor resistance R for a two-phase servomotor
 (a) Is equal to that of a normal induction motor
 (b) Is less than that of a normal induction motor
 (c) Is greater than that of a normal induction motor
 (d) May be less or greater than that of normal induction motor
54. Feedback control systems are
 (a) Insensitive to both forward-and feedback-path parametre changes
 (b) Less sensitive to feedback-path parametre changes than to forward-path parametre changes
 (c) Less sensitive to forward-path parametre changes than to feedback-path parametre changes
 (d) Equally sensitive to forward-and feedback-path parametre changes
55. In sizing a control valve
 (a) A constant flow through the valve is assumed
 (b) A constant pressure drop across the valve is assumed
 (c) An equal percentage opening of the valve is assumed
 (d) A constant pressure downstream and a constant flow through the valve is assumed
56. A temperature control system is usually very sluggish to improve its dynamics if
 (a) A PI controller can be used
 (b) An I controller can be used
 (c) A PID controller with large I and a negligible D action can be used
 (d) A PD controller can be used
57. In a seismic pick-up for getting an output proportional to acceleration it is desirable to have
 (a) A natural frequency very small in comparison to frequency of input and a damping ratio around 0.7
 (b) A natural frequency very large in comparison to frequency of input and a damping ratio around 0.7
 (c) A natural frequency equal to the frequency of input signal and a damping ratio around 0.7
 (d) A natural frequency very small in comparison to frequency of input and a damping ratio higher than unity
58. A First order system with a proportional controller exhibits an offset to step input. The offset can be reduced by
 (a) increasing the gain (b) adding integral mode
 (c) adding derivative mode (d) decreasing the gain.
59. A plant is controlled by a proportional controller. If a time delay element is introduced in the loop then
 1. Gain margin remains the same
 2. Phase margin remains the same
 3. Gain margin decreases
 4. Decreasing the gain
 Chose the correct option:
 (a) 1, 2 are correct (b) 2, 3 are correct
 (c) 2, 3 are correct (d) 3, 4 are correct
60. A synchro transmitter is used with a synchro receiver for the purpose of
 (a) Amplification (b) Error detection
 (c) Remote sensing (d) Addition
61. A current of 5 mA in a standard process controller indicate while zero current output indicates
 (a) Live zero (b) Dead zero
 (c) Full scale (d) Threshold
62. A cascade controller is used when the process
 (a) Gain is too small
 (b) Gain is too large
 (c) Has widely different time constant
 (d) oscillation at the output is not permitted
63. In control system design, gain and phase margins are usually provided to
 (a) Account for the uncertainties in the system
 (b) Make the system respond fast
 (c) Reduce the overshoot in step response
 (d) Reduce the steady state offset
64. First order system with a proportional controller in the negative feedback loop has an offset to a step/input. This offset can be eliminated by
 (a) Adding a derivative mode to the controller
 (b) Adding an integral mode to the controller
 (c) Decreasing the magnitude of the gain of the proportional controller
 (d) Adding a delay in the controller loop
65. Linear variable differential transformer has
 (a) Two primary coils connected in phase and a secondary coil
 (b) Two primary coils connected in opposition and a secondary coil
 (c) One primary coil and two secondary coils. connected in phase
 (d) One primary coil and two secondary coils connected in opposition

66. A second order feedback system is found to be oscillating with a high frequency. The oscillations
- Can be reduced by increasing the proportional action
 - Can be reduced by increasing the integral action
 - Can be reduced by increasing the derivative action
 - Cannot be reduced
67. An integral control is used to
- Improve the transient response
 - Reduce the offset
 - Eliminate the offset
 - Reduce the settling time
68. In a synchro pair, the control transmitter excites the three stator windings of the control transformer. The stator winding voltages will have
- Equal magnitudes but different phases
 - Different magnitudes and different phases
 - Equal magnitudes and phase
 - Different magnitudes but equal phases

69. Consider the following transfer functions:

- $1/(s^2 + s + 1)$
- $4/(s^2 + 2s + 4)$
- $2/(s^2 + 2s + 2)$
- $1/(s^2 + 2s + 1)$
- $3/(s^2 + 6s + 3)$

Which of the above transfer functions represent underdamped second order systems?

- 4 and 5
- 1, 4 and 5
- 1, 2 and 3
- 1, 3 and 5

70. Which one of the following equations gives the steady – state error for a unity Feedback system excited by $u_s(t) + t u_s(t) + [t^2 u_s(t)/2]$?

- $\frac{1}{(2+k_p)} + \frac{1}{k_v} + \frac{1}{k_a}$
- $\frac{1}{(1+k_p)} + \frac{1}{k_v} + \frac{2}{k_a}$
- $\frac{1}{k_p} + \frac{1}{k_v} + \frac{1}{k_a}$
- $\frac{1}{(1+k_p)} + \frac{1}{k_v} + \frac{1}{k_a}$

71. A control system is defined in S – domain. Following points regarding the poles of the transfer function obtained from the characteristic equation were noted

- Poles with positive real part denote stable system
- Complex poles always occur in pairs
- A pole $S = -\sigma$ ($\sigma > 0$) means that the transient response contains exponential decay

Which of the above are correct?

- 1 and 2
- 1 and 3
- 2 and 3
- 1, 2 and 3

72. The Nyquist plot for the closed – loop control system with the loop transfer function $G(s)H(s) = \frac{100}{s(s+10)}$ is plotted. Then, the critical point $(-1, j0)$ is

- Never enclosed
- Enclosed under certain conditions
- Just touched
- Enclosed

73. A minimum phase unity feedback system has a Bode plot with a constant slope of -20 db/decade for all frequencies. What is the value of the maximum phase margin for system?

- 0°
- 90°
- -90°
- 180°

74. The characteristic equation for a third – order system is $q(s) = a_0 s^3 + a_1 s^2 + a_2 s + a_3 = 0$.

For the third-order system to be stable, besides that all the coefficients have to be positive, which one of the following has to be satisfied as a necessary and sufficient condition?

- $a_0 a_1 \geq a_2 a_3$
- $a_1 a_2 \geq a_0 a_3$
- $a_2 a_3 \geq a_1 a_0$
- $a_0 a_3 \geq a_1 a_2$

75. A control system has $G(s)H(s) = K/[s(s+4)](s^2+4s+20)$ ($0 < K < \infty$). What is the number of breakaway points in the root locus diagram?

- One
- Two
- Three
- Zero

76. Which one of the following is the correct expression for the transfer function of an electrical RC phase-lag compensating network?

- $\frac{RCS}{(1+RCS)}$
- $\frac{RC}{(1+RCS)}$
- $\frac{1}{(1+RCS)}$
- $\frac{1}{(1+RCS)}$

77. For a unity feedback system, the origin of the s – plane is mapped in the z – plane by transformation $z = e^{sT}$ to which one of the following?

- Origin
- $1 + j0$
- $-1 + j0$
- $0 + j1$

78. About which one the following is the phase-plane portrait for the non linear system given by $\ddot{X} + f(X, \dot{X})$ and satisfying $f(X, \dot{X}) = f(-X, \dot{X})$, symmetrical?

- $\dot{X}$ -axis
- $\ddot{X}$ -axis
- Both the X and $\dot{X}$ axes
- Neither X nor $\dot{X}$ axes

79. Consider the following statements with regards to the bandwidth of a closed-loop system

In systems where the low frequency magnitude is 0 dB on the Bode diagram, the bandwidth is measured at the -3 dB frequency

- The bandwidth of the closed loop control system is a measurement of the range of fidelity of response of the system
- The speed of response to a step input is proportional to the bandwidth
- The system with the large bandwidth provides slower step response and lower fidelity ramp response

Which of the statements given above are correct?

- (a) 1, 2 and 3 (b) 1, 2 and 4
(c) 1, 3 and 4 (d) 2, 3 and 4

80. Which of the following is the steady state error of a control system with step error, ramp error and parabolic error constants K_p , K_v , and k_a , respectively for the input $(1-t^2)3u(t)$?

- (a) $\frac{3}{1+K_p} - \frac{3}{2k_a}$ (b) $\frac{3}{1+K_p} + \frac{6}{k_a}$
(c) $\frac{3}{1+K_p} - \frac{3}{k_a}$ (d) $\frac{3}{1+K_p} + \frac{6}{k_a}$

81. If the rotor axis of synchro transmitter is along the axis of S_2 stator winding, when will be the electrical zeroing?

- (a) $V_{s1} V_{s2}$ is maximum (b) $V_{s2} V_{s3}$ is maximum
(c) $V_{s2} V_{s3}$ is minimum (d) $V_{s3} V_{s1}$ is minimum

82. The constant M-circles corresponding to the magnitude (M) of the closed loop transfer function of a linear system for values of M greater than one lie in the G-plane and to the

- (a) Right of the $M = 1$ line
(b) Left of the $M = 1$ line
(c) Upper side of the $M = \pm j 1$ line
(d) Lower side of the $M = -j 1$ line

83. What are the order and type of close-loop system for the plant transfer function $G(s) = \frac{K}{s^2(1+Ts)}$ and with unity feedback?

- (a) Two and two (b) Three and two
(c) Two and zero (d) Three and zero

84. The open loop transfer function of a unity feedback control system is given by $G(s) = \frac{K}{s(s+1)}$. If gain K is increased infinity then damping ratio will tend to become

- (a) Zero (b) 0.707
(c) Unity (d) Infinite

85. The characteristic equation of a control system is given by $s(s+4)(s^2+2s+s)+K(s+1)=0$. What are the angles of the asymptotes for the root loci $K \geq 0$?

- (a) $60^\circ, 180^\circ, 300^\circ$ (b) $0^\circ, 180^\circ, 300^\circ$
(c) $120^\circ, 180^\circ, 240^\circ$ (d) $0^\circ, 120^\circ, 240^\circ$

LEVEL 2

1. A series circuit containing R , L and C is excited by a step voltage input. The voltage across the capacitance exhibits oscillations. Damping coefficients (ratio) of circuit is given by

- (a) $\delta = \frac{R}{2\sqrt{LC}}$ (b) $\delta = \frac{R}{LC}$
(c) $\delta = \frac{R}{2\sqrt{C/L}}$ (d) $\delta = \frac{R}{2\sqrt{L/C}}$

2. If a system is represented by the differential equation, $\frac{d^2y}{dt^2} + \frac{6dy}{dt} + 9y = 0$, then the solution y will be of the form

- (a) $k_1 e^{-1} + k_2 e^{-9t}$ (b) $(k_1 + k_2 t) e^{-3t}$
(c) $k e^{-3t} \sin(t + \phi)$ (d) $(k_1 + k_2 t) e^{-3t}$

3. The system described by the equation

$$F(s) = s^4 + 2s^3 + 3s^2 + 6s + K,$$

according to Routh-Hurwitz's criteria, is

- (a) Unstable for all value of K
(b) Stable if $K \geq 0$
(c) Stable if $K < 0$
(d) Stable for all values of K

4. The gain cross-over frequency and bandwidth of a control system are ω_{cu} and ω_{bu} respectively. A phase -lag network is employed for compensating the system. If the gain cross-over frequency and band width of the compensated system are ω_{cc} and ω_{bc} respectively, then

- (a) $\omega_{cc} < \omega_{cu}$; $\omega_{bc} < \omega_{bu}$
(b) $\omega_{cc} < \omega_{cu}$; $\omega_{bc} > \omega_{bu}$
(c) $\omega_{cc} > \omega_{cu}$; $\omega_{bc} < \omega_{bu}$
(d) $\omega_{cc} > \omega_{cu}$; $\omega_{bc} > \omega_{bu}$

5. A linear second-order system with the transfer function $G(s) = \frac{49}{s^2 + 16s + 49}$ is initially at rest and is subjected to a step input signal. The response of the system will exhibit a peak overshoot of

- (a) 16 % (b) 9%
(c) 2% (d) zero

6. The open -loop transfer function of a unity-feedback system is $G(s) = \frac{K(s+10)(s+20)}{s^2(s+2)}$. The closed-loop system will be stable if the value of K is

- (a) 2 (b) 3
(c) 4 (d) 5

7. The open-loop transfer function of a unity feedback control system is $\frac{10}{(s+5)^3}$. The gain margin of the system will be

- (a) 20 dB (b) 40 dB
(c) 60 dB (d) 80 dB

8. The intersection of asymptotes of root-loci of a system with open-loop transfer function

$$G(s)H(s) = \frac{K}{s(s+1)(s+3)}$$

- (a) 1.44 (b) 1.33
(c) -1.44 (d) -1.33

9. The open-loop transfer function of unity feedback control system is

$$G(s) = \frac{K}{s(s+a)(s+b)} \quad a < a < b$$

The system is stable if

- (a) $0 < K < \left(\frac{a+b}{ab}\right)$ (b) $0 < K < \left(\frac{ab}{a+b}\right)$
 (c) $0 < K < ab$ (d) $0 < K < \left(\frac{a}{b}\right)(a+b)$

10. The open-loop transfer function $G(s)$ of a unity feedback control is $[1/s(s+1)]$. The system is subjected to an input $r(t) = \sin t$. The steady-state error will be

- (a) zero (b) 1
 (c) $\sqrt{2} \sin\left(t - \frac{\pi}{4}\right)$ (d) $\sqrt{2} \sin\left(t + \frac{\pi}{4}\right)$

11. A second order system has the damping ratio ζ and un-damped natural frequency of oscillation ω_n . The settling time at 2% tolerance band of the system is

- (a) $2/\zeta\omega_n$ (b) $3/\zeta\omega_n$
 (c) $4/\zeta\omega_n$ (d) $\zeta\omega_n$

12. Which of the following equation represents the constant magnitude locus in G -plane for $M = 1$?

- {x-axis in $\text{Re } G(j\omega)$ and y-axis is $\text{Im } G(j\omega)$ }
 (a) $x = -0.5$ (b) $x = 5$
 (c) $x^2 + y^2 = 1$ (d) $(x+1)^2 + y^2 = 1$

13. The open loop transfer function of system is

$$G(s)H(s) = \frac{k}{(1+s)(1+2s)(1+3s)}$$

The phase crossover frequency ω_c is

- (a) $\sqrt{2}$ (b) 1
 (c) zero (d) $\sqrt{3}$

14. The given characteristic polynomial $s^4 + s^3 + 2s^2 + 2s + 3 = 0$ has

- (a) zero root in RHS of s -plane
 (b) one root in RHS of s -plane
 (c) two roots in RHS of s -plane
 (d) three roots in RHS of s -plane

15. The unit step response of a particular control system is given by $c(t) = 1 - 10e^{-t}$. Then its transfer function is

- (a) $\frac{10}{s+1}$ (b) $\frac{s-9}{s+1}$
 (c) $\frac{1-9s}{s+1}$ (d) $\frac{1-9s}{s(s+1)}$

16. An open loop transfer function of a unity feedback control system has two finite zeros, two poles at origin and two pairs of complex conjugate poles. The slope of high frequency asymptote in Bode magnitude plot will be

- (a) +40 dB/decade (b) 0 dB/decade
 (c) -40 dB/decade (d) -80 dB/decade

17. the transfer function of a phase lead network can be written as

- (a) $\frac{1+sT}{1+s\beta T}; \beta > 1$ (b) $\frac{\alpha(1+sT)}{1+s\alpha T}; \alpha > T$
 (c) $\frac{\beta(1+sT)}{1+s\beta T}; \beta > 1$ (d) $\frac{(1+sT)}{\alpha(1+sT)}; \alpha > 1$

18. A constant N -circle having center at $(-1/2 + j0)$ in the G -plane, represents the phase angle equal to

- (a) 180° (b) 90°
 (c) 45° (d) 0°

19. The constant M -circle represented by the equation $x^2 + 2.25x + y^2 = -1.125$ where $x = \text{Re } [G(j\omega)]$ has $y = \text{Im}$ has the value of M equal to

- (a) 1 (b) 2
 (c) 3 (d) 4

20. The constant N loci represented by the equation $x^2 + x + y^2 = 0$ where $x = \text{Re } |G(j\omega)|$ and $y = \text{Im } |G(j\omega)|$ is for the value of phase angle equal to

- (a) -45° (b) 0°
 (c) $+45^\circ$ (d) $+90^\circ$

21. The characteristic equation of a control system is given by $s^6 + 2s^5 + 8s^3 + 12s^2 + 20s + 16 = 0$.

The number of the roots of the equation which lie on the imaginary axis of s -plane is

- (a) Zero (b) 2
 (c) 4 (d) 6

22. Which one of the following is the transfer function of a linear system whose output is $t^2 e^{-t}$ for a unit step input?

- (a) $\frac{s}{(s+1)^3}$ (b) $\frac{2s}{(s+1)^3}$
 (c) $\frac{1}{s^2(s+1)}$ (d) $\frac{2}{s(s+1)^2}$

23. The maximum value of a controller output is 100 V and is obtained when the input error is IV. If the controller is working at 20% proportional band, the error and output will be respectively

- (a) 0.2 V and 100 V (b) 1 V and 20 V
 (c) 1 V and 120 V (d) 0.2 V and 120 V

24. Which one of the following statements is correct in respect of the theory of stability?

- (a) Phase margin is the phase angle lagging, in short of 180° , at the frequency corresponding to a gain of 10
 (b) Gain margin is the value by which the gain falls short of unity, at a frequency corresponding to 90° phase lag
 (c) Routh-Hurwitz criterion can determine the degree of stability
 (d) Gain margin and phase margin are the measure of the degree of stability

25. All the constant N -circles in G -plane cross the real axis at the fixed points. Which are these points?

- (a) -1 and origin (b) origin and +1
 (c) -0.5 and +0.5 (d) -1 and +1

26. What is the value of M for the constant M circle represented by the equation

$$8x^2 + 18x + 8y^2 + 9 = 0, \text{ where } x = \text{Re } |G(j\omega)| \text{ and } y = \text{Im } |G(j\omega)|$$

- (a) 0.5 (b) 2
 (c) 3 (d) 8

27. The transfer function of phase-lead compensator is given by $G(s) = \frac{1 + aTs}{1 + Ts}$, where $T > 0$, $a > 1$. What is the maximum phase shift provided by this compensator?
- (a) $\tan^{-1} \left(\frac{a+1}{a-1} \right)$ (b) $\tan^{-1} \left(\frac{a-1}{a+1} \right)$
 (c) $\cos^{-1} \left(\frac{a-1}{a+1} \right)$ (d) $\sin^{-1} \left(\frac{a-1}{a+1} \right)$
28. For a stable closed loop system, the gain at phase cross over frequency should always be
- (a) < 20 dB (b) > 6 dB
 (c) < 6 dB (d) < 0 dB
29. Which one of the following expresses the time at which second peak in step response occurs for a second order system?
- (a) $\frac{\pi}{\omega_n \sqrt{1-\xi^2}}$ (b) $\frac{2\pi}{\omega_n \sqrt{1-\xi^2}}$
 (c) $\frac{3\pi}{\omega_n \sqrt{1-\xi^2}}$ (d) $\frac{\pi}{\sqrt{1-\xi^2}}$
30. What is the steady state error for a unity feedback control system having $G(s) = \frac{1}{s(s+1)}$ due to unit ramp input?
- (a) 1 (b) 0.5
 (c) 0.25 (d) $\sqrt{0.5}$
31. The open loop transfer function of a unity negative feedback control system is given by $G(s) = \frac{k}{(s+2)(s+4)(s^2+6s+25)}$. What is the value of k which causes sustained oscillations in the closed loop system?
- (a) 590 (b) 790
 (c) 990 (d) 190
32. The unit step response of a system is $1 - e^{-t}(1+t)$. Which is this system?
- (a) Unstable (b) Stable
 (c) Critically stable (d) Oscillatory
33. The system having characteristic equation $s^4 + 2s^3 + 3s^2 + 2s + k = 0$ is to be used as an oscillator. What are the values of k and the frequency of oscillation ω ?
- (a) $k = 1$ and $\omega = 1$ r/s (b) $k = 1$ and $\omega = 2$ r/s
 (c) $k = 2$ and $\omega = 1$ r/s (d) $k = 2$ and $\omega = 2$ r/s
34. The characteristic equation of a control system is $s^5 + 15s^4 + 85s^3 + 225s^2 + 274s + 120 = 0$. What are the number of roots of the equation which lie to the left of the line $s + 1 = 0$?
- (a) 2 (b) 3
 (c) 4 (d) 5
35. The step size of a stepper motor with 12 rotor tooth is
- (a) 10° (b) 30°
 (c) 60° (d) 120°
36. The characteristic equation $s^3 + 3s^2 + 3s + k = 0$ is stable for which value of k ?
- (a) -6 (b) 0
 (c) 5 (d) 12
37. The impedance, $Z(s) = 25 + 1/3s$ is a
- (a) inductance in series with resistor
 (b) inductance in series with capacitor and resistor
 (c) inductance in series with capacitor
 (d) capacitor in series with resistor
38. Which of the following statements about the equation below, for Roth Hurwitz criterion is true?
 $2s^4 + s^3 + 3s^2 + 5s + 10$
- (a) It has only one root on the imaginary axis
 (b) It has two roots in the right half of the s -plane
 (c) The system is unstable
 (d) The system is stable
39. A second order system exhibit 100% overshoots. Its damping coefficient is
- (a) equal to 0 (b) equal to 1
 (c) less than 1 (d) greater than 1
40. A synchro transmitter-receiver unit is a
- (a) 2 phase AC device
 (b) 3 phase AC device
 (c) DC device
 (d) Single phase AC device
41. For the transfer function $G(s)H(s) = [1/s(s+1)(s+0.5)]$ the phase cross-over frequency is
- (a) 0.5 rad/sec (b) 0.707 rad/sec
 (c) 1.732 rad/sec (d) 2 rad/sec
42. A unity feedback control system has a forward path transfer function equal to $42.25/s(s+6.5)$. The unit step response of this system starting from rest will have its maximum value at a time equal to
- (a) 0 sec (b) 0.567 sec
 (c) 5.6 sec (d) infinity
43. A plant has the following transfer function $G(s) = 1/(s^2 + 0.2s + 1)$. For a step input it is required that the response settles to within 2% of its final value. The plant setting time is
- (a) 20 sec (b) 40 sec
 (c) 35 sec (d) 45 sec
44. The maximum phase shift that can be provided by a lead compensator with transfer function, $G_c(s) = [(1+6s)/(1+2s)]$ is
- (a) 15° (b) 30°
 (c) 45° (d) 60°
45. The transfer function of a compensating network is of form $(1 + \alpha Ts)/(1 + Ts)$. If this is a phase-lag network the value of α should be
- (a) exactly equal to 0 (b) between 0 and 1
 (c) exactly equal to 1 (d) greater than 1

46. If the open-loop transfer function of the system is

$$G(s)H(s) = \frac{K(s+10)}{s(s+8)(s+16)(s+72)}$$

then a closed loop pole will be located at $s = -12$ when the value of K is

- (a) 4355 (b) 5760
(c) 9600 (d) 9862
47. Assuming the transient response of a second order system to be given by

$$c(t) = 1 - \frac{e^{-\delta t}}{\sqrt{1-\delta^2}} \sin[(\omega_n \sqrt{1-\delta^2})t + \theta]$$

the settling time for the 5% criterion will be

- (a) 1/2 sec (b) 3/4 sec
(c) 5/4 sec (d) 4 sec

48. For the second order transfer function

$$T(s) = [4/(s^2 + 2s + 4)]$$

The maximum resonance peak will be

- (a) 4 (b) 4/3
(c) 2 (d) $2/\sqrt{3}$

49. In a two phase ac servomotor, the rotor has a resistance R and a reactance X . The torque-speed characteristic of the servomotor will be linear provided that

- (a) $(X/R) \ll 1$ (b) $(X/R) \gg 1$
(c) $(X/R) = 1$ (d) $X^2 = R$

50. For the system $\ddot{x} + ax\dot{x} + bx = 0$ the equation for the phase – plane isocline of slope ‘m’ is

- (a) $m^2 + am + b = 0$ (b) $m = -ax - \frac{bx}{\dot{x}}$
(c) $m = ax + \frac{bx}{x}$ (d) $m^2 + axm + b = 0$

51. A system with transfer function $G(s) = \frac{s}{(1+s)}$ is subjected to

a sinusoidal input $r(t) = \sin \omega t$. In steady-state, the phase angle of the output relative to the input at $\omega = 0$ and $\omega = \infty$ will be respectively

- (a) 0° and -90° (b) 0° and 0°
(c) 90° and 0° (d) 90° and -90°
52. A system has fourteen poles and two zeros. The slope of its highest frequency asymptote in its magnitude plot is
- (a) -40 dB/decade (b) -240 dB/decade
(c) -280 dB/decade (d) -320 dB/decade

53. The open-loop transfer function of a feedback control system is

$$\frac{K}{s(s^2 + 3s + 6)}$$

- (a) exist at $(-1 \pm j1)$ (b) exist at $\left(-\frac{3}{2} \pm \sqrt{\frac{15}{16}}\right)$

- (c) exists at origin (d) do not exist

54. $[-a \pm jb]$ are the complex conjugate roots of the characteristic equation of a second order system. Its damping coefficient and natural frequency will be respectively

(a) $\frac{b}{\sqrt{a^2 + b^2}}$ and $\sqrt{a^2 + b^2}$

(b) $\frac{b}{\sqrt{a^2 + b^2}}$ and $a^2 + b^2$

(c) $\frac{a}{\sqrt{a^2 + b^2}}$ and $\sqrt{a^2 + b^2}$

(d) $\frac{a}{\sqrt{a^2 + b^2}}$ and $a^2 + b^2$

55. A unity feedback control system has a forward path transfer function $G(s) = \frac{10(1+4s)}{s^2(1+s)}$. If the system is subjected to an

input $r(t) = 1 + t + \frac{t^2}{2} (t \geq 0)$, the steady-state error of the system will be

- (a) zero (b) 0.1
(c) 10 (d) infinity

56. For the function $X(s) = \frac{1}{s(s+1)^3(s+2)}$, the residues associated with the simple poles at $s = 0$ and $s = -2$ are respectively

- (a) $\frac{1}{2}$ and $\frac{1}{2}$ (b) 1 and 1
(c) -1 and -1 (d) $-\frac{1}{2}$ and $\frac{1}{2}$

57. The state-variable description of a linear autonomous system is

$$\dot{X} = AX \text{ where, } X \text{ is a state vector and } A = \begin{bmatrix} 0 & 2 \\ 2 & 0 \end{bmatrix}$$

The poles of the system are located at

- (a) -2 and $+2$ (b) $-2j$ and $+2j$
(c) -2 and -2 (d) $+2$ and $+2$

58. Consider the state transition matrix

$$\phi(s) = \begin{bmatrix} \frac{s+6}{s^2+6s+5} & \frac{1}{s^2+6s+5} \\ \frac{-5}{s^2+6s+5} & \frac{s}{s^2+6s+5} \end{bmatrix}$$

The eigenvalues of the system are

- (a) 0 and -6 (b) 0 and $+6$
(c) 1 and -5 (d) -1 and -5

59. The Laplace transform of a transportation lag of five seconds is

- (a) $\exp(-5s)$ (b) $\exp(5s)$
(c) $\frac{1}{s+5}$ (d) $\exp\left(\frac{-s}{5}\right)$

60. The phase angle of the system $G(s) = \frac{s+5}{s^2+4s+9}$ varies between

- (a) 0° and 90° (b) 0° and -90°
(c) 0° and -180° (d) -90° and -180°

61. A second order control system is defined by the following differential equation

$$4 \frac{d^2 c(t)}{dt^2} + 8 \frac{dc(t)}{dt} + 16 c(t) = 16 u(t)$$

The damping ratio and natural frequency for this system are respectively

- (a) 0.25 and 2 rad/s (b) 0.50 and 2 rad/s
(c) 0.25 and 4 rad/s (d) 0.25 and 4 rad/s

62. The characteristic equation of a feedback control system is given by $s^3 + 5s^2 + (K+6)s + K = 0$. In the root loci diagram, the asymptotes of the root loci for large 'K' meet at a point in the s -plane whose coordinates are

- (a) (2, 0) (b) (-1, 0)
(c) (-2, 0) (d) (-3, 0)

63. If the Nyquist plot cuts the negative real axis at a distance of 0.4 then the gain margin of the system is

- (a) 0.4 (b) -0.4
(c) 4% (d) 2.5

64. The transfer function of a phase lead compensator is given by $\frac{1+aTs}{1+Ts}$ where, $a > 1$ and $T > 0$. The maximum phase shift provided by such a compensator is

- (a) $\tan^{-1}\left(\frac{a+1}{a-1}\right)$ (b) $\tan^{-1}\left(\frac{a-1}{a+1}\right)$
(c) $\sin^{-1}\left(\frac{a+1}{a-1}\right)$ (d) $\sin^{-1}\left(\frac{a-1}{a+1}\right)$

65. Consider the single input, single output system with its state variables representation

$$X' = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & -3 \end{bmatrix} X + \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} U$$

$$Y = [1 \ 0 \ 2] X$$

The system is

- (a) Neither controllable nor observable
(b) Controllable but not observable
(c) Uncontrollable but observable
(d) Both controllable and observable

66. A particular control system is described by the following state equations:

$$X' = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} X + \begin{bmatrix} 0 \\ 1 \end{bmatrix} U \text{ and } Y = [2 \ 0] X$$

The transfer function of this system is

- (a) $\frac{Y(s)}{U(s)} = \frac{1}{2s^2 + 3s + 1}$ (b) $\frac{Y(s)}{U(s)} = \frac{2}{2s^2 + 3s + 1}$
(c) $\frac{Y(s)}{U(s)} = \frac{1}{s^2 + 3s + 2}$ (d) $\frac{Y(s)}{U(s)} = \frac{2}{s^2 + 3s + 2}$

67. A linear time invariant system, initially at rest when subjected to a unit step input gave a response $c(t) = te^{-t}$ ($t \geq 0$). The transfer function of the system is

- (a) $\frac{s}{(s+1)^2}$ (b) $\frac{1}{s(s+1)^2}$
(c) $\frac{1}{(s+1)^2}$ (d) $\frac{1}{s(s+1)}$

68. The torque-speed characteristic of two-phase induction motor is largely affected by

- (a) voltage (b) $\frac{R}{X}$ and speed
(c) $\frac{X}{R}$ (d) supply voltage frequency

69. In order to use Routh Hurwitz Criterion for determining the stability of sampled data system, the characteristic equation $1 + G(z)H(z) = 0$ should be modified by using bilinear transform of

- (a) $z = r + 1$ (b) $z = r - 1$
(c) $z = \frac{r-1}{r+1}$ (d) $z = \frac{r+1}{r-1}$

70. The system matrix of a discrete system is given by

$$A = \begin{bmatrix} 0 & 1 \\ -3 & -5 \end{bmatrix}$$

The characteristic equation is given by

- (a) $z^2 + 5z + 3 = 0$ (b) $z^2 - 3z - 5 = 0$
(c) $z^2 + 3z + 5 = 0$ (d) $z^2 + z + 2 = 0$

71. Given the transfer function $G(s) = \frac{121}{s^2 + 13.2s + 121}$ of a system. Which of the following characteristics does it have?

- (a) Over damped and settling time 1.1s
(b) Under damped and settling time 0.6s
(c) Critically damped and settling time 0.8s
(d) Under damped and settling time 0.707s

72. Which of the following are the characteristics of the root locus

$$\text{of } G(s)H(s) = \frac{K(s+5)}{(s+1)(s+3)}?$$

1. It has one asymptote
2. It has intersection with $j\omega$ -axis
3. It has two real axis intersections
4. It has two zeros at infinity

Select the correct answer using the codes given below:

Codes:

- (a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1 and 3

The characteristic equation of a system is given by $3s^4 + 10s^3 + 5s^2 + 2 = 0$. The system is

- (a) stable (b) marginally stable
(c) unstable (d) neither (a), (b) nor (c)

73. Indicate which one of the following transfer function represents phase lead compensator?

- (a) $\frac{s+1}{s+2}$ (b) $\frac{6s+3}{6s+2}$
(c) $\frac{s+5}{3s+2}$ (d) $\frac{s+8}{s^2+5s+6}$

74. A linear time-invariant system is described by the following dynamic equation

$$\frac{dx(t)}{dt} = Ax(t) + Bu(t)$$

$$y(t) = Cx(t)$$

where $A = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix}$, $B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$, $C = [1 \quad 1]$

The system is

- (a) Both controllable and observable
- (b) Controllable but unobservable
- (c) Observable but uncontrollable
- (d) Both uncontrollable and unobservable

75. The state-space representation in phase-variable form for the transfer function

$$G(s) = \frac{2s+1}{s^2+7s+9} \text{ is}$$

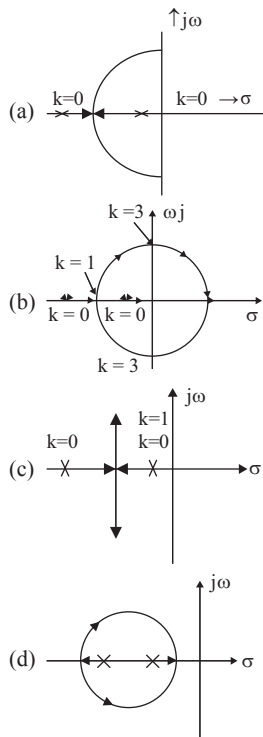
- (a) $x = \begin{bmatrix} 0 & 1 \\ -9 & -7 \end{bmatrix} x + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u; y = [1 \ 2] x$
- (b) $x = \begin{bmatrix} 1 & 0 \\ -9 & -7 \end{bmatrix} x + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u; y = [0 \ 1] x$
- (c) $x = \begin{bmatrix} -9 & 0 \\ 0 & -7 \end{bmatrix} x + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u; y = [2 \ 0] x$
- (d) $x = \begin{bmatrix} 9 & -7 \\ 1 & 0 \end{bmatrix} x + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u; y = [1 \ 2] x$

LEVEL 3

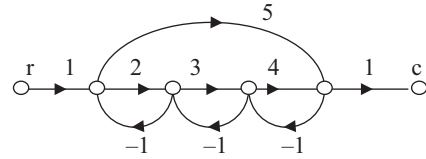
1. The transfer function of a closed loop system is

$$T(s) = \frac{K}{s^2 + (3-K)s + 1}$$

Where, K is forward path gain The root locus plot of the system is

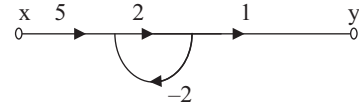


2. In the signal flow graph of figure, the gain c/r will be:



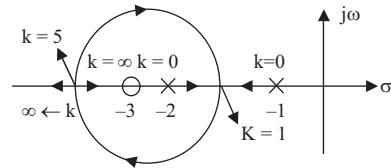
- (a) 11/9
- (b) 22/15
- (c) 24/23
- (d) 44/23

3. In the signal flow graph of figure, y/x equals



- (a) 3
- (b) (5/2)
- (c) 2
- (d) None of the above

4. The root-locus diagram for a closed-loop feedback system is shown in the figure. The system is over-damped



- (a) Only if $0 \leq K \leq 1$
- (b) Only if $1 < K < 5$
- (c) Only if $K > 5$
- (d) $(0) \leq K < 1$ or $K > 5$

5. An electrical system and its signal-flow graph representation are shown in the figure (A) and (B) respectively. The values of G_2 and H , respectively, are

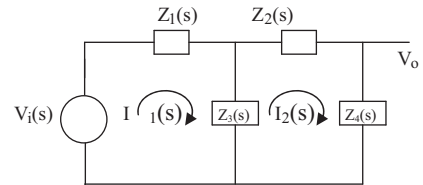


Fig. A

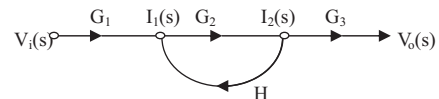
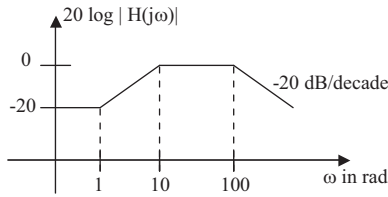


Fig. B

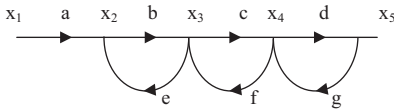
- (a) $\frac{Z_3(s)}{Z_2(s) + Z_3(s) + Z_4(s)}$, $\frac{-Z_3(s)}{Z_1(s) + Z_3(s)}$
- (b) $\frac{-Z_3(s)}{Z_2(s) - Z_3(s) + Z_4(s)}$, $\frac{-Z_3(s)}{Z_1(s) + Z_3(s)}$
- (c) $\frac{Z_3(s)}{Z_2(s) + Z_3(s) + Z_4(s)}$, $\frac{Z_3(s)}{Z_1(s) + Z_3(s)}$
- (d) $\frac{-Z_3(s)}{Z_2(s) - Z_3(s) + Z_4(s)}$, $\frac{Z_3(s)}{Z_1(s) + Z_3(s)}$

12. Consider the Bode magnitude plot shown in the figure. The transfer function $H(s)$ is



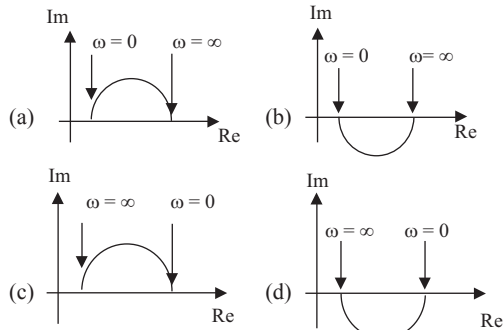
- (a) $\frac{(s+10)}{(s+1)(s+100)}$ (b) $\frac{10(s+1)}{(s+1)(s+100)}$
 (c) $\frac{10^2(s+1)}{(s+1)(s+100)}$ (d) $\frac{10^3(s+100)}{(s+1)(s+10)}$

13. Consider the signal flow graph shown in the figure. The gain $[x_5/x_1]$ is

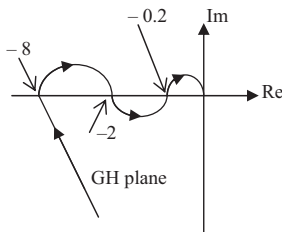


- (a) $\frac{1-(be+cf+dg)}{abc}$
 (b) $\frac{bedg}{1-(be+cf+dg)}$
 (c) $\frac{abcd}{1-(be+cf+dg)+bedg}$
 (d) $\frac{1-(be+cf+dg)+bedg}{abcd}$

14. Which one of the following polar diagrams corresponds to a lag network?



15. The polar diagram of a conditionally stable system for open gain $K = 1$ is shown in the figure. The open loop transfer function of the system is known to be stable. The closed loop system is stable for

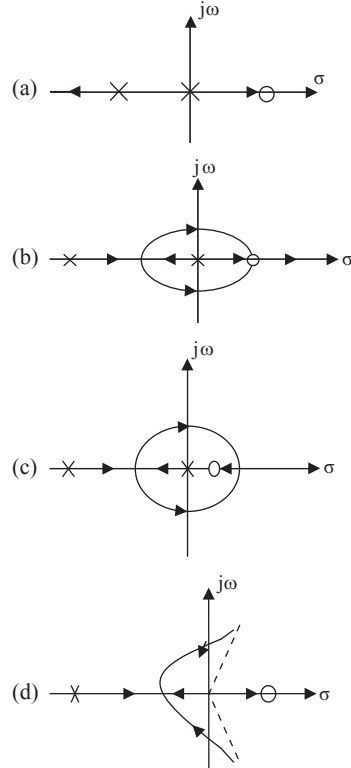


- (a) $K < 5$ and $[1/2] < K < [1/8]$
 (b) $K < [1/8]$ and $[1/2] < K < 5$
 (c) $K < [1/8]$ and $5 < K$
 (d) $K > [1/8]$ and $K < 5$

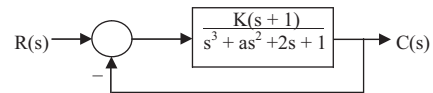
16. An unity feedback system is given as,

$$G(s) = \frac{K(1-s)}{s(s+3)}$$

Indicate the correct root locus diagram.

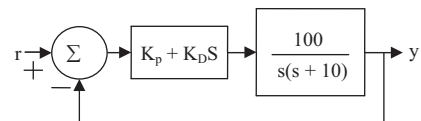


17. The positive values of “K” and “a” so that the system shown in the figure below oscillates at a frequency of 2 rad/sec respectively are



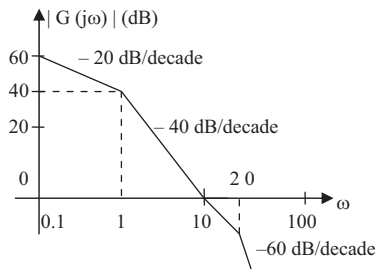
- (a) 1, 0.75 (b) 2, 0.75
 (c) 1, 1 (d) 2, 2

18. A control system with a PD controller is shown in the figure. If the velocity error constant $K_v = 1000$ and the damping ratio $\xi = 0.5$, then the values of K_p and K_D are:



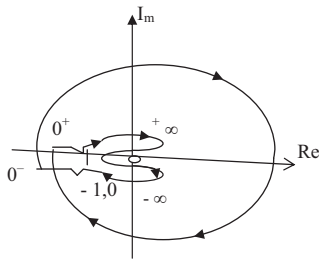
- (a) $K_p = 100, K_D = 0.09$ (b) $K_p = 100, K_D = 0.9$
 (c) $K_p = 10, K_D = 0.09$ (d) $K_p = 10, K_D = 0.9$

19. The asymptotic Bode plot of a transfer function is as shown in the figure. The transfer function $G(s)$ corresponding to this Bode plot is



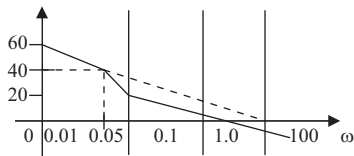
- (a) $\frac{1}{(s+1)(s+20)}$ (b) $\frac{1}{s(s+1)(s+20)}$
 (c) $\frac{100}{s(s+1)(s+20)}$ (d) $\frac{100}{s(s+1)(1+0.05s)}$

20. Which of the following is the transfer function of a system having the Nyquist plot in figure?



- (a) $\frac{K}{s(s+2)^2(s+5)}$ (b) $\frac{K}{s^2(s+2)(s+5)}$
 (c) $\frac{K(s+1)}{s^2(s+2)(s+5)}$ (d) $\frac{K(s+1)(s+3)}{s^2(s+2)(s+5)}$

21. The system having the Bode magnitude plot as shown in the figure has the transfer function

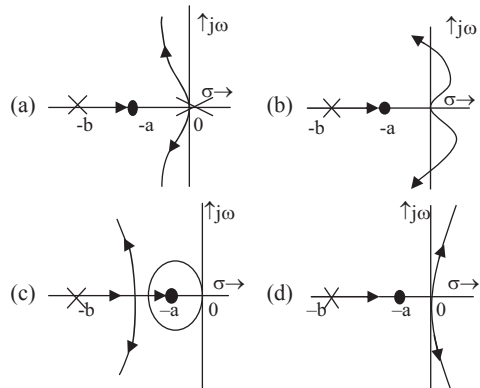


- (a) $\frac{60(s+0.01)(s+0.1)}{s^2(s+0.05)^2}$ (b) $\frac{10(1+10s)}{s(1+20s)}$
 (c) $\frac{3(s+0.05)}{s(s+0.1)(s+1)}$ (d) $-\frac{5(s+0.1)}{s(s+0.05)}$

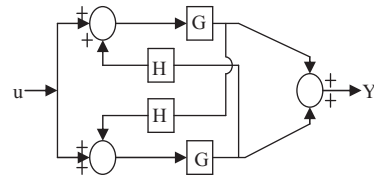
22. A unity feedback system has an open-loop transfer function of the form

$$KG(s) = \frac{K(s+a)}{s^2(s+b)}; b > a$$

Which of the loci shown in the figure can be valid root-loci for the system?

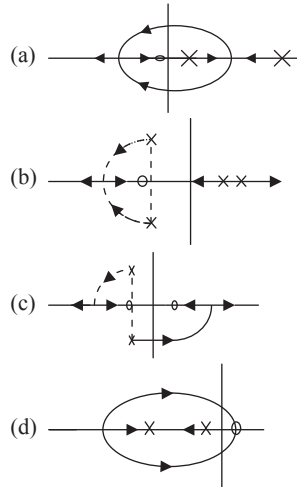


23. The overall transfer function of the system in figure is

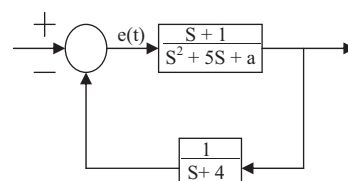


- (a) $\frac{G}{1-GH}$ (b) $\frac{2G}{1-GH}$
 (c) $\frac{GH}{1-GH}$ (d) $\frac{2G}{1-H}$

24. Which of the following figure(s) represent valid root loci in the s -plane for positive K ? Assume that the system has a transfer function with real co-efficient



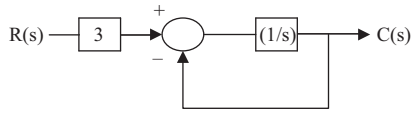
25. For what values of 'a' does the system shown in the figure have a zero steady state error [i.e., $\lim_{t \rightarrow \infty} e(t)$] for a step input?



- (a) $a = 0$ (b) $a = 1$
 (c) $a^3 \geq 4$ (d) for no value of 'a'

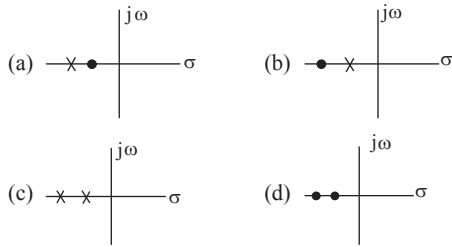
9.42 ■ Control Systems

26. The matrix of any state-space equations for the transfer function $[C(s)/R(s)]$ of the system shown below in figure is



- (a) $\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$ (b) $\begin{pmatrix} 0 & 1 \\ 0 & -1 \end{pmatrix}$
 (c) $[-1]$ (d) $[3]$

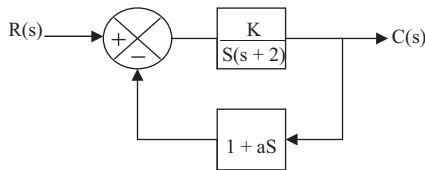
27. The pole-zero configuration of a phase-lead compensator is given by



28. For the system shown in the figure, with a damping ratio δ of 0.7 and an un-damped natural frequency ω_n of 4 rad/sec, the value of K and a are

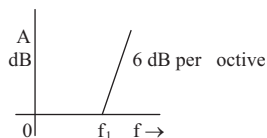
- (a) $K = 4, a = 0.35$ (b) $K = 8, a = 0.455$
 (c) $K = 16, a = 0.225$ (d) $K = 64, a = 0.9$

29. For block diagram shown in the figure, $C(s)/R(s)$ is given by



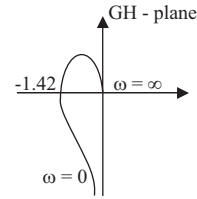
- (a) $\frac{G_1 G_2 G_3}{1 + H_2 G_2 G_3 + H_1 G_1 G_2}$
 (b) $\frac{G_1 G_2 G_3}{1 + G_1 G_2 G_3 H_1 G_2}$
 (c) $\frac{G_1 G_2 G_3}{1 + G_1 G_2 G_3 H_1 + G_1 G_2 G_3 H_2}$
 (d) $\frac{G_1 G_2 G_3}{1 + G_1 G_2 G_3 H_1}$

30. The function corresponding to the Bode plot of given figure is



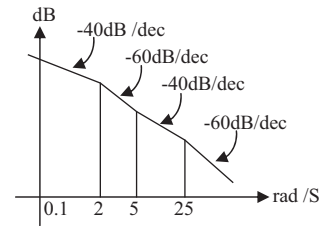
- (a) $A = jff_1$ (b) $A = 1/(1 - jff_1)$
 (c) $A = 1/(1 + jff_1)$ (d) $A = 1 + jff_1$

31. The polar plot of a type-1, 3-pole, open-loop system is shown in the figure. The closed-loop system is



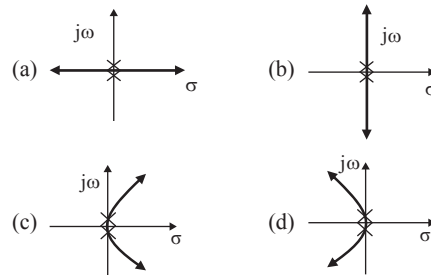
- (a) Always stable
 (b) Marginally stable
 (c) Unstable with one pole on the right half s -plane
 (d) Unstable with two poles on the right half s -plane

32. The asymptotic approximately of the log-magnitude versus frequency plot of a minimum phase system with real poles and one zero is shown in the figure. Its transfer function is

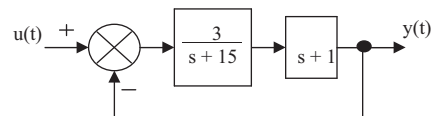


- (a) $\frac{20(s+5)}{s(s+2)(s+25)}$ (b) $\frac{10(s+5)}{(s+2)^2(s+25)}$
 (c) $\frac{20(s+5)}{s^2(s+2)(s+25)}$ (d) $\frac{50(s+5)}{s^2(s+2)(s+25)}$

33. A unity feedback system as an open loop transfer function, $G(s) = [K/s^2]$. The root locus plot is

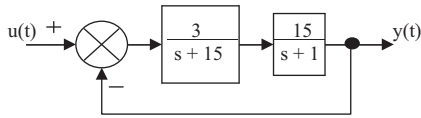


34. The block diagram shown in the figure gives a unity feedback closed loop control system. The steady state error in the response of the above system to unit step input is



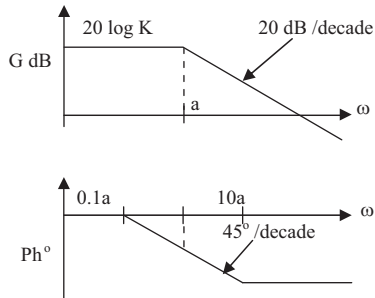
- (a) 25 % (b) 0.75 %
 (c) 6 % (d) 33 %

35. The roots of the closed loop characteristic equation of the system shown in the figure are



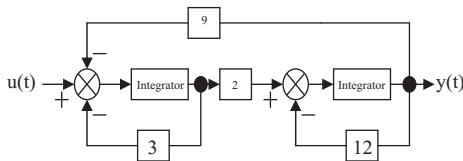
- (a) -1 and -15 (b) 6 and 10
(c) -4 and -15 (d) -6 and 10

36. The asymptotic Bode plot of the transfer function $[K/1 + (s/a)]$ is given in the figure. The error in phase angle and dB gain at a frequency of $\omega = 0.5a$ are respectively



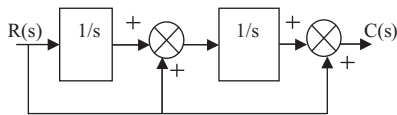
- (a) 4.0° , 0.97 dB (b) 5.7° , 3 dB
(c) 4.9° , 3 dB (d) 5.7° , 0.97 dB

37. The block diagram of a control system is shown in the figure. The transfer function $G(s) = Y(s)/U(s)$ of the system is



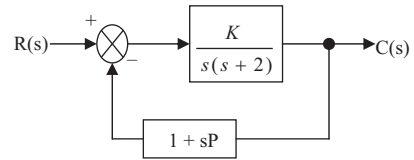
- (a) $\frac{1}{18 \left[1 + \frac{s}{12}\right] \left[1 + \frac{s}{3}\right]}$ (b) $\frac{1}{27 \left[1 + \frac{s}{6}\right] \left[1 + \frac{s}{9}\right]}$
(c) $\frac{1}{27 \left[1 + \frac{s}{12}\right] \left[1 + \frac{s}{9}\right]}$ (d) $\frac{1}{27 \left[1 + \frac{s}{9}\right] \left[1 + \frac{s}{3}\right]}$

38. For block diagram shown in the figure the transfer function $\frac{C(s)}{R(s)}$ is equal to



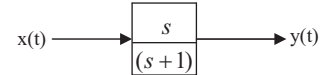
- (a) $\frac{s^2 + 1}{s^2}$ (b) $\frac{s^2 + s + 1}{s^2}$
(c) $\frac{s^2 + s + 1}{s}$ (d) $\frac{1}{s^2 + s + 1}$

39. The block diagram of a closed loop control system is given by figure the values of K and P such that the system has a damping ratio of 0.7 and an undamped natural frequency ω_n of 5 rad/sec, are respectively equal to



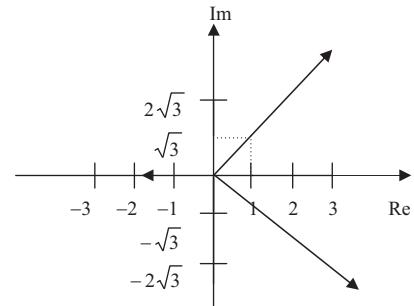
- (a) 20 and 0.3 (b) 20 and 0.2
(c) 25 and 0.3 (d) 25 and 0.2

40. In the system shown in the figure, the input $x(t) = \sin t$. In the steady-state, the response $y(t)$ will be



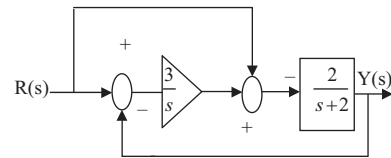
- (a) $\frac{1}{\sqrt{2}} \sin(t - 45^\circ)$ (b) $\frac{1}{\sqrt{2}} \sin(t + 45^\circ)$
(c) $\sin(t - 45^\circ)$ (d) $\sin(t + 45^\circ)$

41. Figure shows the root locus plot (location of poles not given) of a third order system whose open loop transfer function is



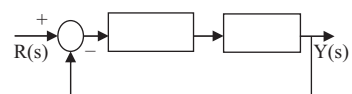
- (a) $\frac{K}{s^3}$ (b) $\frac{K}{s^2(s+1)}$
(c) $\frac{K}{s(s^2+1)}$ (d) $\frac{K}{s(s^2-1)}$

42. When subjected to a unit step input, the closed loop control system shown in the figure will have a steady state error of



- (a) -1.0 (b) -0.5
(c) 0 (d) 0.5

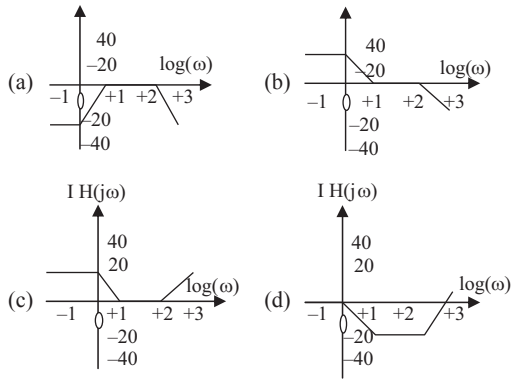
43. If the compensated system shown in the figure has a phase margin of 60° at the crossover frequency of 1 rad/sec, then value of the gain K is



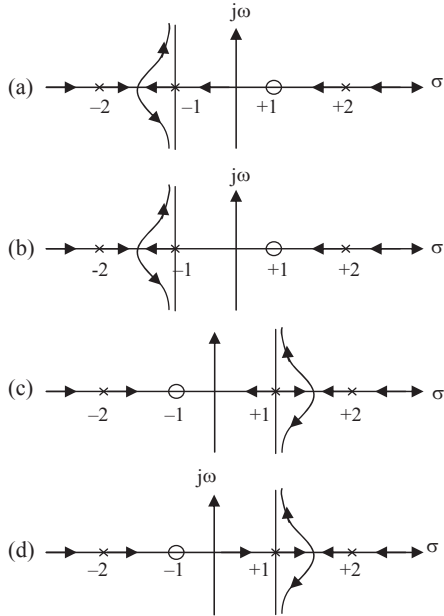
- (a) 0.366 (b) 0.732
(c) 1.366 (d) 2.738

44. The Bode magnitude plot of

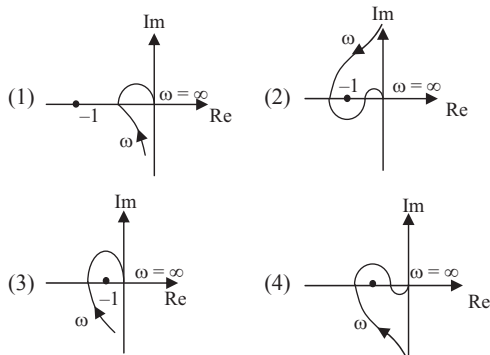
$$H(j\omega) = \frac{10^4(1+j\omega)}{(10+j\omega)(100+j\omega)^2} \text{ is}$$



45. A closed-loop system has the characteristic function. $(s^2 - 4)(s + 1) + (s - 1) = 0$ Its root locus plot against K is

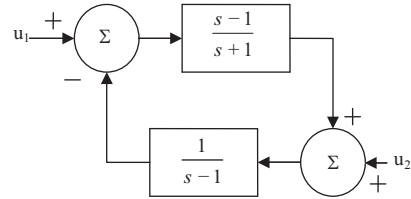


46. Consider the following Nyquist plots of loop transfer function over $\omega = 0$ to $\omega = \infty$. Which of these plots represents a stable closed loop system?



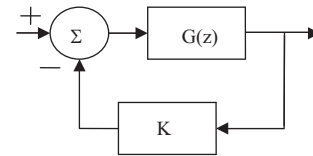
- (a) (1) only (b) all, except (1)
(c) all, except (3) (d) (1) and (2) only

47. The system shown in the figure is



- (a) Stable
(b) Unstable
(c) Conditionally stable
(d) Stable for input u_1 , but unstable for input u_2

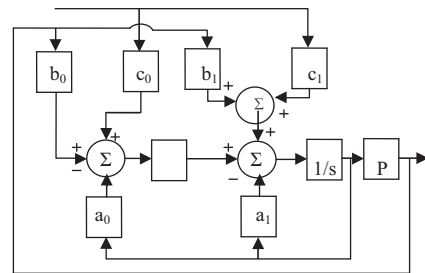
48. Consider the discrete-time system shown in the figure where, the impulse response of $G(z)$ is $g(0)=0, g(1)=g(2)=1, g(3)=g(4)=\dots=0$



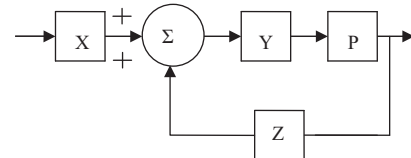
The system is stable for range of values of K

- (a) $[-1, 1/2]$ (b) $[-1, 1]$
(c) $[-1/2, 1]$ (d) $[-1/2, 2]$

49. The system shown in the figure below



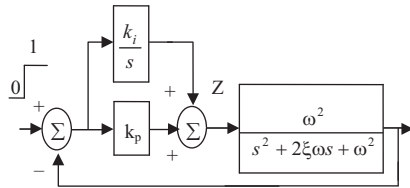
can be reduced to the form:



With

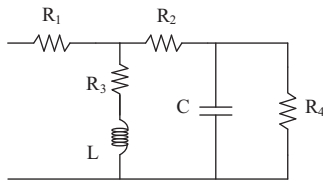
- (a) $X = c_0 s + c_1, Y = \frac{1}{s^2 + a_0 s + a_1}, Z = b_0 s + b_1$
(b) $X = 1, Y = \frac{c_0 s + c_1}{s^2 + a_0 s + a_1}, Z = b_0 s + b_1$
(c) $X = c_1 s + c_0, Y = \frac{b_1 s + b_0}{s^2 + a_1 s + a_0}, Z = 1$
(d) $X = c_1 s + c_0, Y = \frac{1}{s^2 + a_1 s + a_0}, Z = b_1 s + b_0$

50. Consider the feedback control system shown below which is subjected to a unit step input. The system is stable and has the following parameters $k_p = 4$, $k_i = 10$, $\omega = 500$ and $\xi = 0.7$

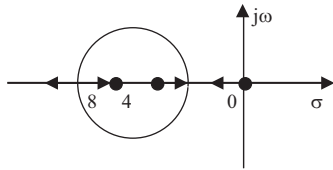


The steady state value of z is

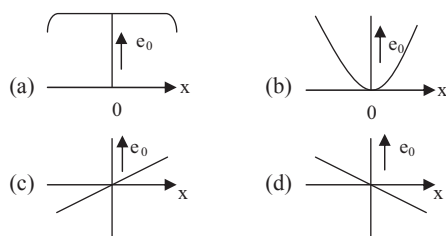
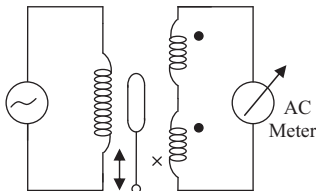
- (a) 1 (b) 0.25
(c) 0.1 (d) 0
51. The minimum number of states required to describe the network shown in the figure



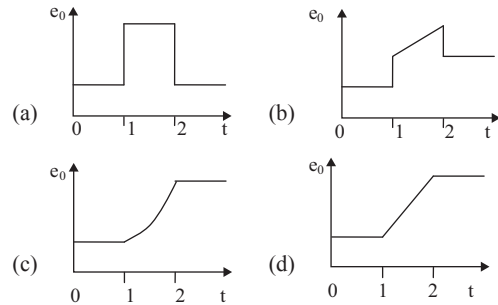
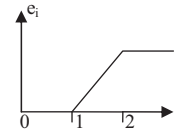
- (a) 1 (b) 2
(c) 3 (d) 4
52. The root locus plot of a unity feedback system is shown in the figure. The system transfer function has the form



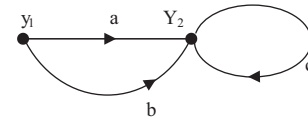
- (a) $\frac{K}{s(s+4)(s+8)}$ (b) $\frac{K(s+8)}{s(s+4)}$
(c) $\frac{K(s+4)}{s(s+8)}$ (d) $\frac{Ks}{(s+4)(s+8)}$
53. The two secondary coils of an LVDT have wrongly been connected as shown in the figure. Then the Input-output relationship would be



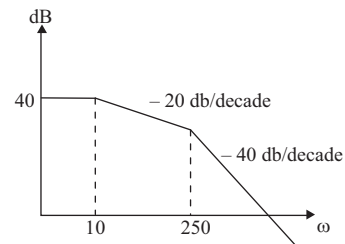
54. The input error voltage to a PD-controller, e_i is shown in the figure. The output voltage of the controller e_o is



55. The transfer function between y_2 and y_1 in figure

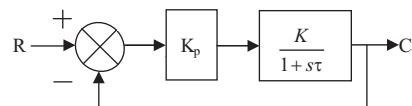


- (a) $a + b$ (b) $(a + b)c$
(c) $[(a + b)/(1 - c)]$ (d) $[(a + b)/(1 + c)]$
56. The asymptotic Bode plot for the gain magnitude of a minimum phase system $G(s)$ is shown in the figure



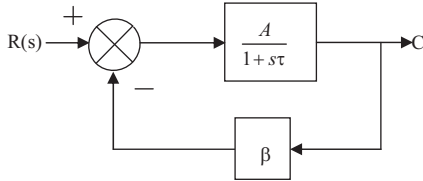
The transfer function is $G(s) =$

- (a) $\frac{100}{\left(1 + \frac{s}{10}\right)\left(1 + \frac{s}{250}\right)}$ (b) $\frac{40}{s(s+250)}$
(c) $\frac{100}{(s+10)(s+250)}$ (d) $\frac{100s}{(s+1)(s+250)}$
57. The steady state error for the feedback control system shown in the figure when subjected to a unit step input is



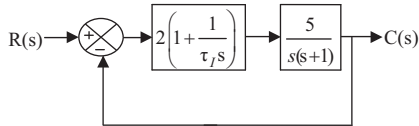
- (a) Zero (b) $\frac{1}{1 + KK_p}$
(c) $\frac{KK_p}{1 + KK_p}$ (d) Infinite

58. In the feedback scheme shown in the figure the time constant of the closed loop system will be



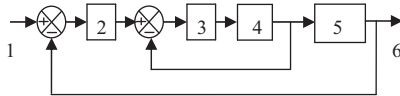
- (a) $A\beta\tau$ (b) $[(1+A\beta)\tau]$
(c) τ (d) $\tau/(1+A\beta)$

59. The closed loop control system shown in the figure has $\tau_1 > 0$. The system will remain stable for all τ_1 in the range



- (a) $\tau_1 < 0.5$ (b) $0.5 < \tau_1 < 1.0$
(c) $\tau_1 < 1.0$ (d) $\tau_1 > 1.0$

60. In figure K_1 and K_2 are proportional controllers. For the control system to remain stable, the upper limits of K_1 and K_2 are

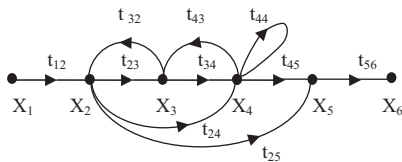


Where, 1 = $x(t)$, 2 = K_2 , 3 = K_1 , 4 = $\frac{1}{s+1}$

$$5 = \frac{8}{(s+2)(s+4)} \quad 6 = y(t)$$

- (a) ∞, ∞ (b) 1, ∞
(c) $\infty, 10$ (d) 10, 1

61. The sum of combinations of two non-touching loops in the following signal flow graph is



- (a) $t_{23}t_{32} + t_{44}$ (b) $t_{23}t_{32} + t_{34}t_{43}$
(c) $t_{23}t_{32} + t_{34}t_{44} + t_{44}$ (d) $t_{24}t_{43}t_{32} + t_{44}$

62. What is the effect of phase lead compensator on gain cross over frequency (ω_{cg}) and on the bandwidth (ω_b)?

- (a) Both are increased
(b) ω_{cg} is increased but ω_b is decreased
(c) ω_{cg} is decreased but ω_b is increased
(d) Both are decreased

63. A system function has a pole at $s = 0$ and a zero at $s = -1$. The constant multiplier is unity. For an excitations cost, what is the steady-state response?

- (a) $\sqrt{2} \sin(t + 45^\circ)$ (b) $\sqrt{2} \sin(t - 45^\circ)$
(c) $\sin(t - 45^\circ)$ (d) $\sin t$

64. A system function $N(s) = \frac{V(s)}{I(s)} = \frac{s+3}{4s+5}$,

The system is initially at rest. If the excitation $i(t)$ is a unit step. Which of the following are the initial and steady-state values of $v(t)$?

Initial value	Steady-state values
(a) 0	3/5
(b) 1/4	0
(c) 3/5	1/4
(d) 1/4	3/5

65. Consider the following statements:

The gain cross over point is the point where

- The magnitude $|G(j\omega)| = 1$ in polar plot
- The magnitude curve of $G(j\omega)$ crosses zero dB line in Bode plot
- Magnitude vs phase plot touches zero dB loci in Nichol's chart

Which of the statement given above are correct?

- (a) Only 1 and 2 (b) Only 1 and 3
(c) Only 2 and 3 (d) 1, 2 and 3

66. The transfer function of a phase lead compensator is found to

be of the form $\frac{s+z_1}{s+P_1}$ and that of a lag compensator to be of the

form $\frac{s+z_2}{s+P_2}$,

Then which of the following conditions must be satisfied?

- (a) $z_1 > p_1$ and $z_2 > p_2$ (b) $z_1 > p_1$ and $z_2 < p_2$
(c) $z_1 < p_1$ and $z_2 < p_2$ (d) $z_1 < p_1$ and $z_2 > p_2$

67. An electromechanical closed-loop control system has the transfer function

$$\frac{C(s)}{R(s)} = \frac{k}{s(s^2 + s + 1)(s + 4) + k}$$

Which one of the following is correct?

- (a) The system is stable for all positive values of k
(b) The system is unstable for all values of k
(c) The system is stable for values of k between zero and 3.36
(d) The system is stable for values of k between 1.6 and 2.45

68. A particular control system yielded a steady-state error of 0.20 for unit step input. A unit integrator is cascaded to this system and unit ramp input is applied to the modified system. What is the value of steady-state error for this modified system?

- (a) 0.10 (b) 0.15
(c) 0.20 (d) 0.25

69. In order to recover the original signal from the sampled one, what is the condition to be satisfied for sampling frequency ω_s and highest frequency component ω_m ?

- (a) $\omega_m < \omega_s \leq 2\omega_m$ (b) $\omega_s \geq 2\omega_m$
 (c) $\omega_s < \omega_m$ (d) $\omega_s = \omega_m$

70. The characteristic equation of second-order sampled data system is given by

$$F(z) = a_2 z^2 + a_1 z + a_0 = 0, a_2 > 0$$

What are the stability constraints for this system?

1. $a_2 + a_1 + a_0 > 0$
2. $a_2 - a_1 + a_0 > 0$
3. $|a_0| < a_2$
4. $|a_0| < a_2$
5. $|a_1| < a_2$

Select the correct answer using the code given below:

Code:

- (a) Only 1, 2 and 3 (b) Only 1, 2 and 4
 (c) Only 1, 3 and 5 (d) Only 2, 3 and 5

71. Consider the following statements:

1. For a linear discrete system to be stable all the roots of the characteristic equation $1 + GH(z) = 0$ should be inside the unit circle
2. The Bode diagram of a sampled data system can be constructed using bilinear transformation
3. The root locus technique can be used for sampled data system without requiring any modifications

Which of the statements given above is/are correct?

- (a) Only 1 (b) Only 2 and 3
 (c) Only 1 and 3 (d) 1, 2 and 3

72. The open loop transfer function for unity feedback system is given by

$$\frac{5(1+0.1s)}{s(1+5s)(1+20s)}$$

Consider the following statements:

1. The steady-state error for a step input of magnitude 10 is 2
2. The steady-state error for a ramp input of magnitude 10 is 2
3. The steady-state error for an acceleration input of magnitude 10 is infinite

Which of the statements given above are correct?

- (a) Only 1 and 2 (b) Only 1 and 3
 (c) Only 2 and 3 (d) 1, 2 and 3

73. Consider the following equation:

$$2s^4 + s^3 + 3s^2 + 5s + 10 = 0$$

How many roots does this equations have in the right half of s-plane?

- (a) One (b) Two
 (c) Three (d) Four

74. $4 \frac{d^2 y}{dt^2} + 36y = 36x$

Consider the following statements in connection with the differential equation given above:

1. The natural frequency of the response is 6 rad/s
2. The response is always oscillatory
3. The percentage overshoot is 10% and damping ratio of the system is 0.6
4. Both system time constant and settling time are infinity

Which of the statements given above are correct:

- (a) 1 and 3 (b) 2 and 4
 (c) 1, 2 and 3 (d) 2, 3 and 4

75. Consider the network function

$$H(s) = \frac{2(s+3)}{(s+2)(s+4)}$$

What is the steady-state response due to a unit step input?

- (a) 4/3 (b) 1/2
 (c) 3/4 (d) 1

ANSWER KEYS

LEVEL 1

1. (a)	2. (a)	3. (d)	4. (b)	5. (d)	6. (b)	7. (d)	8. (c)	9. (a)	10. (b)
11. (d)	12. (c)	13. (a)	14. (c)	15. (c)	16. (c)	17. (c)	18. (a)	19. (d)	20. (a)
21. (a)	22. (a)	23. (b)	24. (b)	25. (c)	26. (b)	27. (b)	28. (c)	29. (d)	30. (c)
31. (c)	32. (c)	33. (d)	34. (c)	35. (b)	36. (c)	37. (d)	38. (d)	39. (c)	40. (a)
41. (c)	42. (a)	43. (c)	44. (a)	45. (d)	46. (a)	47. (b)	48. (c)	49. (b)	50. (b)
51. (b)	52. (b)	53. (b)	54. (c)	55. (c)	56. (d)	57. (b)	58. (b)	59. (a)	60. (b)
61. (a)	62. (d)	63. (a)	64. (a)	65. (d)	66. (b)	67. (a)	68. (a)	69. (c)	70. (d)
71. (c)	72. (a)	73. (b)	74. (d)	75. (c)	76. (c)	77. (b)	78. (b)	79. (a)	80. (d)
81. (d)	82. (b)	83. (b)	84. (a)	85. (a)					

LEVEL 2

1. (d)	2. (b)	3. (a)	4. (a)	5. (d)	6. (d)	7. (b)	8. (d)	9. (c)	10. (a)
11. (c)	12. (a)	13. (b)	14. (c)	15. (c)	16. (c)	17. (b)	18. (b)	19. (c)	20. (d)
21. (c)	22. (b)	23. (a)	24. (d)	25. (a)	26. (c)	27. (d)	28. (d)	29. (c)	30. (a)

31. (b)	32. (c)	33. (c)	34. (c)	35. (b)	36. (b)	37. (c)	38. (b)	39. (a)	40. (d)
41. (b)	42. (b)	43. (b)	44. (b)	45. (b)	46. (b)	47. (b)	48. (d)	49. (a)	50. (b)
51. (c)	52. (b)	53. (a)	54. (c)	55. (d)	56. (a)	57. (a)	58. (d)	59. (a)	60. (b)
61. (b)	62. (c)	63. (d)	64. (d)	65. (a)	66. (d)	67. (a)	68. (b)	69. (d)	70. (a)
71. (b)	72. (d)	73. (a)	74. (a)	75. (b)					

LEVEL 3

1. (b)	2. (d)	3. (c)	4. (d)	5. (c)	6. (a)	7. (d)	8. (d)	9. (d)	10. (a)
11. (b)	12. (c)	13. (c)	14. (d)	15. (b)	16. (c)	17. (b)	18. (b)	19. (d)	20. (d)
21. (d)	22. (a)	23. (b)	24. (a)	25. (a)	26. (c)	27. (a)	28. (c)	29. (a)	30. (d)
31. (c)	32. (d)	33. (b)	34. (a)	35. (d)	36. (a)	37. (b)	38. (b)	39. (d)	40. (b)
41. (a)	42. (c)	43. (c)	44. (a)	45. (b)	46. (a)	47. (d)	48. (b)	49. (d)	50. (a)
51. (b)	52. (b)	53. (a)	54. (d)	55. (c)	56. (a)	57. (b)	58. (d)	59. (d)	60. (a)
61. (a)	62. (a)	63. (a)	64. (d)	65. (d)	66. (d)	67. (c)	68. (d)	69. (b)	70. (b)
71. (c)	72. (c)	73. (b)	74. (b)	75. (c)					

COMMUNICATION SYSTEMS

10.1 RANDOM SIGNALS AND NOISE

Random Signals and Noise

Signals can be classified as deterministic and random. Deterministic signals can be completely specified as functions of time. Random signals are those whose value cannot be predicted in advance.

1. Probability density function

Suppose that a random experiment is repeated n times. If an event A occurs n_A times, then its probability $p(A)$ is defined as

$$p(A) = p(x_k) = \lim_{n \rightarrow \infty} \frac{n_A}{n} = p(A) = \frac{N_A}{N}$$

2. $p(A + B) = p(A) + p(B) - p(AB)$

$p(AB)$ is joint probability

3. Mutually exclusive event $P(AB) = 0$

$$p(A + B) = p(A) + p(B)$$

4. Conditional probability

$$p(A|B) = p(A) \cdot p(B/A)$$

$$p(AB) = p(B) \cdot p(A/B)$$

$$p\left(\frac{A}{B}\right) = \frac{p(AB)}{p(B)}$$

$$p\left(\frac{A}{B}\right) = \frac{p(A) \cdot p(B/A)}{p(B)} \rightarrow \text{Bay's relation}$$

where, (B/A) is probability of happening B , when A has already happened.

5. Statistically independent event

$$\begin{aligned} p(AB) &= p(A) \cdot p(B/A) \\ &= p(A) \cdot p(B) \end{aligned}$$

i.e., if event A and B are not dependent on each other, the conditional probability simply equal to unconditional probability i.e.,

$$p(B/A) = p(B) \text{ and } p(A/B) = p(A)$$

6. Cumulative distributive function (CDF)

The distributive function yields the probability that the random variable will be less than or equal to some specified value x_j thus,

$$P(X \leq x_i) = \sum_{k=1}^j p(x_k) = p(x_1) + p(x_2) + p(x_3) + \dots$$

7. Statistical Average/Moments Expectation of random variable/(mean)

$$m = \bar{x} = E(x) = \sum_{k=1}^K x_k p(x_k)$$

This is dc value of random variable.

$$\text{where, } p(x) = \frac{N_{io}}{N}$$

$$\bar{x} = E(x) = p_1 x_1 + p_2 x_2 + p_3 x_3 + \dots$$

8. Second moment or Mean square value

$$\overline{x^2} = E(X^2) = \sum_{k=1}^{\infty} x_k^2 p(x_k)$$

This is total value i.e., $(ac + dc)$.

9. Variance σ^2

$$\sigma^2 = E(X^2) - [E(X)]^2 = X^2 - (\bar{x})^2 = \bar{x}^2 - m^2$$

It gives an ac value.

This is measure of broadness or spreading of density function.

10. Standard deviation = σ

11. Joint CDF

$$P[X \leq x_n; Y \leq y_m] = \sum_{k=1}^n \sum_{L=1}^m p(x_k, y_L)$$

$$(a) \sum_{k=1}^{\infty} \sum_{L=1}^{\infty} p(x_k, y_L) = 1$$

$$(b) = \sum_{k=1}^n \sum_{L=-\infty}^{\infty} = \sum_{k=1}^n p(x_k)$$

Continuous Probability Theory

Random Value = X ; Possible Value = x .

1. **Probability function = $p(x)$ or $f(x)$**
2. **Cumulative distributive function (CDF)**

$$P(x_1) = \int_{-\infty}^{x_1} p(x) dx = P(-\infty < x \leq x_1)$$

$$p(x) = \frac{\delta}{\delta x} [P(x)]$$

Where, $[P(x)] = CDF$

3. **If X and Y are statistically independent**

$$p(x, y) = p(x) p(y/x)$$

$$p(x, y) = p(x) \cdot p(y)$$

$$p(y/x) = p(y); p(x/y) = p(x)$$

4. **Joint probability density function**

$$p(x, y) = p(x/y) \cdot p(y)$$

$$= p(y/x) \cdot p(x)$$

$$P\left(\frac{x}{y}\right) = \frac{p(x, y)}{p(y)}$$

$$= \frac{p(y/x) \cdot p(x)}{p(y)} \text{ ----Bays relation.}$$

5. **Joint CDF**

$$P[-\infty < X < x; -\infty < Y < y]$$

$$P(x, y) = \int_{-\infty}^x \int_{-\infty}^y p(x, y) dx \cdot dy$$

$$= \int_{-\infty}^x p(x) dx \int_{-\infty}^y p(y) dy$$

---- if x and y are independent

6. **mean $\bar{x} = E(X) = \int_{-\infty}^{\infty} x p(x) dx = m$**

7. **Second moment or mean square value**

$$\overline{X^2} = E(X^2) = \int_{-\infty}^{\infty} x^2 p(x) dx$$

8. **Variance $\sigma^2 = E(X^2) - [E(X)]^2$**

$$= \bar{X}^2 - (\bar{x})^2 = \bar{X}^2 - m^2$$

9. $\int_{-\infty}^{\infty} p(x) dx = 1$; $p(-\infty < x < \infty)$

$$10. \int_{-\infty}^y \int_{-\infty}^{\infty} p(x, y) dx \cdot dy = \int_{-\infty}^y p(y) dy$$

Note: Root mean square value = $\sqrt{\overline{X^2}}$.

Cumulative Distribution Function (CDF)

The probability function of X is the function $F_X(x) = P(X \leq x)$ defined for every x from $-\infty$ to ∞ .

Properties of $F_X(x)$:

1. $F(-\infty) = 0$
2. $F(\infty) = 1$
3. $0 \leq F(x) \leq 1$
4. $F(x_1) \leq F(x_2)$ if $x_1 < x_2$
5. $F = P\{x_1 < X \leq x_2\} = F(x_2) - F(x_1)$
6. $F(x+) = F(x)$
where $F(x^+) = \lim_{0 < \varepsilon \rightarrow 0} F(x + \varepsilon)$.

Probability Density Function (PDF)

The probability density function (pdf) of X is defined as

$$f(x) = \frac{dF(x)}{dx}$$

Properties of $f(x)$:

1. $f(x) \geq 0$
2. $\int_{-\infty}^{\infty} f(x) dx = 1$
3. $F(x) = \int_{-\infty}^x f(x) dx$
4. $P(x_1 \leq X \leq x_2) = \int_{-\infty}^{x_2} f(x) dx$

If X is discrete, then

$$f(x) = \sum_i P(x_i) \delta(x - i)$$

where $P(x_i) = P(X = x_i)$ and $\delta(x)$ is the impulse function.

5. $F(\infty, \infty) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) dx dy = 1$.

6. **Marginal Distribution:**

The function $F(x)$ and $F(y)$ are called marginal probability distribution if they are derived by

$$F(x) = F(x, \infty) = \int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} f(x, y) dy$$

$$F(y) = F(\infty, y) = \int_{-\infty}^{\infty} dy \int_{-\infty}^{\infty} f(x, y) dx.$$

Moments and Variance

- (a) The n th moment of X is defined by

$$m_n = E[X^n] = \int_{-\infty}^{\infty} x^n f(x) dx$$

(b) The n th central moment of X is defined by

$$E(X - m_x)^n = \int_{-\infty}^{\infty} (x - m_x)^n f(x) dx$$

where $m_x = E[X]$.

$$\sigma_x^2 = E[X^2] - m_x^2 = E[X^2] - (E[X])^2.$$

Gaussian PDF

A random variable X is called normal (or Gaussian) if its pdf is of the form

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma^2} e^{-\frac{(x-m)^2}{2\sigma^2}}$$

Gaussian CDF of X is

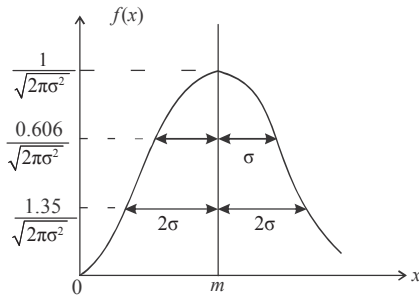
$$\begin{aligned} F(x) &= \frac{1}{\sqrt{2\pi}\sigma^2} \int_{-\infty}^x e^{-\frac{(x-m)^2}{2\sigma^2}} dx \\ &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{x-m}{\sigma}} e^{-\frac{\lambda^2}{2}} d\lambda \end{aligned}$$

This integral cannot be evaluated in a closed form and must be evaluated numerically. It is convenient to use the function $Q(z)$, defined as

$$Q(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-\frac{\lambda^2}{2}} d\lambda$$

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma^2} e^{-\frac{(x-m)^2}{2\sigma^2}}$$

And is plotted in figure below m and σ^2 are the average value and variance of $f(x)$.



The Gaussian density function

Fig. 10.1

It can be deduced from figure that when $x - m = \pm\sigma$, $f(x)$ has fallen to 0.606 of its peak value. When $x = m \pm 2\sigma$, $f(x)$ falls to 0.135 of the peak value.

If mean = 0 i.e., $m = 0$

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma^2} e^{-\frac{x^2}{2\sigma^2}}$$

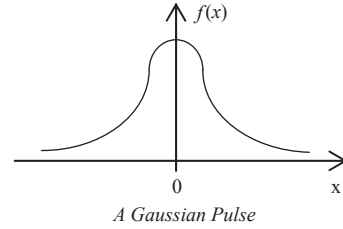


Fig. 10.2

Gaussian Process

where, $m_y \rightarrow$ mean

$\sigma_y^2 \rightarrow$ variance.

Property 1: If a Gaussian process $x(t)$ is applied to a stable linear filter, then the random process $y(t)$ is developed. The output of the filter is also Gaussian.

Property 2: Consider the set of random variables or samples $x(t_1), x(t_2), x(t_3), \dots$ obtained by observing a random process $x(t)$ at time $t_1, t_2, \dots$. If the process is Gaussian then this set of random variable is to-----

The Rayleigh PDF

The Rayleigh PDF is defined by

$$f(r) = \begin{cases} \frac{r}{\alpha^2} e^{-\frac{r^2}{2\alpha^2}}, & 0 \leq r \leq \infty \\ 0, & r < 0 \end{cases}$$

A plot of $f(r)$ as a function of r is shown in figure below.

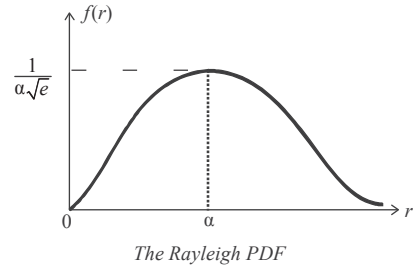


Fig. 10.3

The mean value is given by $\bar{R} = \sqrt{\frac{\pi}{2}} \alpha$,

the mean squared value v , and

the variance $\sigma_r^2 = \left(2 - \frac{\pi}{2}\right) \alpha^2$

SUM of Random Variable

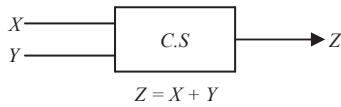


Fig. 10.4

x, y, z – arbitrary value

$p(x)$ and $p(y)$ are specified

Probability density function of $Z = X + Y$ if find $p(z)$.

Method 1

$$Z = X + Y$$

$$z = x + y ; y = (z - x)$$

$$p(z) = p(x) * p(y)$$

$$p(z) = \int_{-\infty}^{\infty} p(x) \cdot p(y) dx$$

$$p(z) = \int_{-\infty}^{\infty} p(x) \cdot p(z - x) dx$$

Method 2

$$F_x(f) = FT[p(x)]$$

$$F_y(f) = FT[p(y)]$$

$$F_z(f) = FT[p(z)]$$

$$F_z(f) = F_x(f) \cdot F_y(f)$$

$$F(z) = FT^{-1}[F_z(f)]$$

$$\text{Mean: } m_z = m_x + m_y$$

$$\text{Variance: } \sigma_z^2 = \sigma_x^2 + \sigma_y^2$$

Output of PDF of a random variable which is function of some other variable

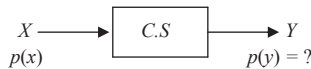


Fig. 10.5

where, $p(x)$ and $y =$ function of x are specified.

Then, $p(y) = p(x) | (dx/dy) |$

Example

Correlation Function

A random process $x(t)$ being neither periodic nor finite, energy has auto correlation function defined by

Case 1: Random signal

$$R(\tau) = \lim_{T \rightarrow \infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t) x(t - \tau) dt.$$

Case 2: Periodic signal (Power signal)

$$R(\tau) = \frac{1}{T_o} \int_{-T_o/2}^{T_o/2} x(t) x(t - \tau) dt$$

where, $T_o =$ time period

$\tau =$ Time lag parametre

Case 3: Pulse type of signal (Energy signal) i.e., Non periodic

$$R(\tau) = \int_{-\infty}^{\infty} x(t) x(t - \tau) dt$$

Properties of $R(\tau)$

1. If the random process is stationary, then the auto correlation function $R(t_1, t_2)$ only depends on the time difference between t_1 and t_2

$$R(t_1, t_2) = R(t_1, t_1 + \tau) = R(\tau).$$

2. If the random process is ergodic then

$$(a) R(\tau) = \lim_{T \rightarrow \infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t) \cdot x(t - \tau) dt.$$

$$= \langle x(t) \cdot x(t - \tau) \rangle \text{ --- Time average} \\ = R(\tau)$$

- (b) Auto correlation is even function of τ

$$R(\tau) = R(-\tau)$$

$$\text{i.e., } \langle x(t) \cdot x(t - \tau) \rangle = \langle x(t) \cdot x(t + \tau) \rangle$$

- (c) $R(0) \geq |R(\tau)|$ i.e., Which indicate that autocorrelation can never exceed its value of $\tau = 0$

- (d) $R_{xx}(0) = E[x^2(t)]$

3. The auto correlation function and the spectral density of a given function form a Fourier transform pair.

$$R(\tau) \leftrightarrow G(\omega) \text{ ---- Wiener Kintchen Theorem}$$

$$G(\omega) = FT[R(\tau)]$$

$$= \int_{-\infty}^{\infty} R(\tau) e^{-j\omega\tau} d\tau$$

Let, $x(t)$ be a periodic function of time with time period T

$\therefore x(t)$ Can be written in term of exponential Fourier series

$$x(t) = \sum_{n=-\infty}^{\infty} F_n e^{jn\omega_o t}$$

$$\omega_o = \frac{2\pi}{T}$$

$$\text{where, } F_n = \frac{1}{T} \int_0^T x(t) e^{-jn\omega_o t} dt.$$

Spectral density of periodic signal.

$$G(\omega) = 2\pi \sum_{n=-\infty}^{\infty} |F_n|^2 \delta(\omega - n\omega_o)$$

They are summarized in the following:

1. $\bar{x} = \langle x(t) \rangle$ is equal to the dc level of the signal.
2. $[\bar{x}]^2 = \langle x(t)^2 \rangle$ is equal to the normalized power in the dc component.

3. $R_{XX}(0) = \langle x^2(t) \rangle$ is equal to the total average normalized power.
4. $\bar{\sigma}_x^2 = \langle x^2(t) \rangle$ is equal to the average normalized power in the time-varying or ac component of the signal.
5. $\bar{\sigma}_x$ is equal to the rms value of the ac component of the signal.

White Noise

White noise is defined as any random process whose spectral density is constant and thus independent of frequency.

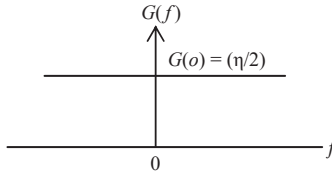


Fig. 10.6

$$G(f) = G_0 = \text{constant}; -\infty < f < +\infty$$

$$F^{-1} [G(f)] = R(\tau) = \int_{-\infty}^{\infty} G_0 e^{j\omega\tau} d\omega$$

$$= G_0 \delta(\tau) = (\eta/2) \delta(t)$$

It is usually assumed that mean of white noise is zero.

Note: Reference is made to Inverse Fourier transform.

$$f(t) = FT^{-1} [F(\omega)] = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) e^{j\omega t} d\omega$$

$$= \frac{1}{2\pi} \int_{-\infty}^{\infty} 1 \cdot e^{j\omega t} d\omega = (1/2\pi) \cdot 2\pi \delta(t) = \delta(t)$$

$$\text{since, } \left(FT[1] = \int_{-\infty}^{\infty} 1 \cdot e^{-j\omega t} dt = 2\pi \delta(\omega) \right)$$

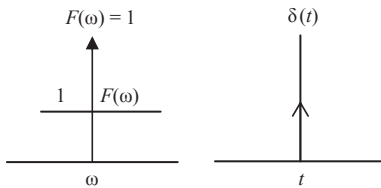


Fig. 10.7

Band Limited White Noise

Physically, white noise is not realizable because infinite power requirement, however, it is often possible to consider the process as white over a specified frequency range.

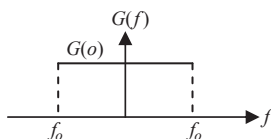


Fig. 10.8

$$R(\tau) = \int_{-f_o}^{f_o} G_0 e^{j\omega\tau} d\omega = 2f_o G_0 \frac{\sin \omega_o \tau}{\omega_o \tau}$$

Average power for Band limited white noise

$$R(0) = \int_{-f_o}^{f_o} G_0 d\omega = 2f_o G_0 \text{ Volt}^2$$

Spectral Density

Which express the Energy/Average power in a signal (i.e., waveform on 1Ω basis) as a function of frequency.

$$|F(\omega)|^2 = \text{Energy spectral density; J/Hz}$$

→ It is a real and even function of ω

$$G_E(\omega) = |F(\omega)|^2$$

$$E = \frac{1}{2\pi} \int_{-\infty}^{\infty} G_E(\omega) d\omega$$

$$\text{where } G_E(\omega) \text{ is even function} = \frac{1}{\pi} \int_{-\infty}^{\infty} G_E(\omega) d\omega$$

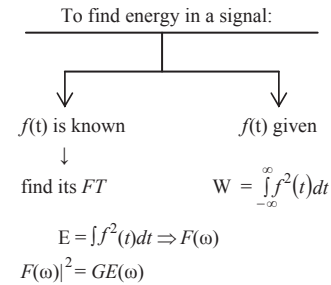


Fig. 10.9

$$E = \frac{1}{2\pi} \int_{-\infty}^{\infty} G_E(\omega) d\omega$$

Input output relation between transfer function

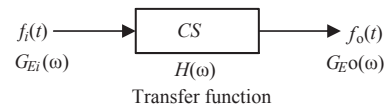


Fig. 10.10

$$H(\omega) = \frac{FT[f_o(t)]}{FT[f_i(t)]} = \frac{F_o(\omega)}{F_i(\omega)}; F_o(\omega) = H(\omega) F_i(\omega)$$

Input output relation between spectral densities

$$\Rightarrow |F_o(\omega)|^2 = [H(\omega)]^2 |F_i(\omega)|^2 = |H(\omega)|^2 |F_i(\omega)|^2$$

$$G_{Eo}(\omega) = |H(\omega)|^2 G_{Ei}(\omega).$$

Power Spectrum Density

Let $R_{XX}(\tau)$ be the auto-correlation of $X(t)$. Then the power spectral density (or power spectrum) of $X(t)$ is defined by the Fourier transform of $R_{XX}(\tau)$.

$$S_{XX}(\omega) = \int_{-\infty}^{\infty} R_{XX}(\tau) e^{-j\omega\tau} d\tau$$

$$R_{XX}(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} S_{XX}(\omega) e^{j\omega\tau} d\omega$$

Equation are known as the Wiener-Khinchin relations.

Properties of $S_{XX}(\omega)$

1. $S_{XX}(\omega)$ is real and $S_{XX}(\omega) \geq 0$
2. $S_{XX}(-\omega) = S_{XX}(\omega)$
3. $\frac{1}{2\pi} \int_{-\infty}^{\infty} S_{XX}(\omega) d\omega = R_{XX}(0) = E[X^2(t)]$

Properties of Power Spectral Density

$$S_x(f) = \int_{-\infty}^{\infty} R_x(\tau) e^{-j2\pi f\tau} d\tau$$

$$R_x(\tau) = \int_{-\infty}^{\infty} S_x(f) e^{j2\pi f\tau} df$$

The auto correlation function and spectral density are Fourier transform Pair.

Property (1)

The zero frequency value of a power spectral density of a stationary process equal the total area under the graph of the auto correlation function, that is

$$S_x(0) = \int_{-\infty}^{\infty} R_x(\tau) d\tau \quad ; \text{ for } \tau = 0$$

Property (2)

The mean square value of the stationary process equals the total area under the graph of power spectral density, that is

$$E[x^2(t)] = \int S_x(f) df$$

$$R_x(0) = E[x^2(t)] \text{ for } \tau = 0.$$

Property (3)

The power spectral density of stationary process is always non-negative: That is

$$S_x(f) \geq 0 \text{ for all } f$$

Property (4)

The power spectral density of a real-valued random process is an even function of frequency: i.e.,

$$S_x(-f) = S_x(f).$$

Property (5)

The power spectral density, appropriately normalized has the properties usually associated with a probability function.

$$p_x(f) = \frac{S_x(f)}{\int_{-\infty}^{\infty} S_x(f) df}$$

Sinusoidal wave with random phase.

Power Spectral Density

defined for power signal i.e., random, or periodic signal.

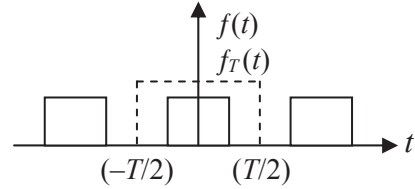


Fig. 10.11

$f_T(t) = f(t); (-T/2) \leq t \leq (T/2)$
 power contained in the signal $f(t)$
 = Average energy contained in the signal $f_T(t)$
 as $T \rightarrow \infty$

$$\text{Power (P)} = \lim_{T \rightarrow \infty} \frac{1}{T} \int_{-T/2}^{T/2} (f_T(t))^2 dt$$

Power Spectral Density

$$G_P(\omega) = G(\omega) = \lim_{T \rightarrow \infty} \frac{1}{T} (F_T(\omega))^2$$

$$G(\omega) = \lim_{T \rightarrow \infty} \frac{|F_T(\omega)|^2}{T}$$

--- using parse Val's theorem similarly

Power contained in the signal $f(t)$

$$P = \frac{1}{2\pi} \int_{-\infty}^{\infty} G(\omega) d\omega = \frac{2}{2\pi} \int_0^{\infty} G(\omega) d\omega = \int_{-\infty}^{\infty} G(\omega) df$$

Note: $G(\omega)$ retain only information of magnitude spectrum the phase information is lost.

Input output relationship between power spectral density

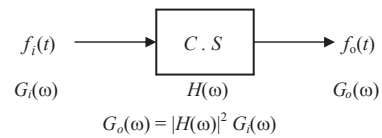


Fig. 10.12

Power density spectrum: This represents the energy per unit Bandwidth (either Positive or Negative

$$G(\omega) = \lim_{T \rightarrow \infty} \frac{|F(\omega)|^2}{T}$$

Special Case

Mathematical representation of periodic function

$$f(t) = \sum_{n=-\infty}^{\infty} F_n e^{jn\omega_o t}$$

$$F(\omega) = 2\pi \sum_{n=-\infty}^{\infty} F_n \delta(\omega - n\omega_o)$$

Power spectral density

$$G(\omega) = 2\pi \sum_{n=-\infty}^{\infty} |F_n|^2 \delta(\omega - n\omega_o)$$

$$\text{where, } F_n = \frac{1}{T} \int_{-T/2}^{T/2} f(t) e^{-jn\omega_o t} dt$$

Noise

Noise is an unwanted signal of an unpredicted nature. It can be man made or natural. The internally generated noise due to circuit components.

Thermal Noise

The noise generated in a resistance or resistive component of any impedance is random and is referred to variously as thermal, agitation, white or Johnson Noise. It is due to rapid motion of molecules, atoms and electron of which resistor is constructed.

Noise Power generated by resistor is

$\propto$ absolute temperature

$\propto$ Bandwidth over which Noise power is measured

$$P_n = kT\delta f$$

$$= \frac{V^2}{R_L} = \left(\frac{V_n/2}{2} \right)^2 = \frac{V_n^2}{4R}$$

$$V_n^2 = 4 R P_n$$

$$= 4 kTR \delta f$$

$G_v(f)$ = Spectral density of thermal noise

$G_v(f)$ = Depend upon

(1) Absolute temperature

(2) Magnitude of resistance

$$G_v(f) = 2 k TR \rightarrow \text{Volt}^2/\text{Hz}$$

Mean Square Noise Voltage (Noise power)

$$\overline{V_n^2} = \int_{-\infty}^{\infty} G_v(f) df \rightarrow \text{Volt}^2$$

$$\begin{aligned} \overline{V_n^2} &= G_v(f) \int df = G_v(f) 2 \Delta f = 2 k TR 2 \Delta f \\ &= 4 kTR \Delta f \text{ Volt}^2 \end{aligned}$$

RMS noise voltage

$$V_{rms} = \sqrt{\overline{V_n^2}} = \sqrt{4 kTR \Delta f} \text{ Volt.}$$

Two Resistance in Series

$$R = R_1 + R_2$$

$$G_v(f) = 2 kTR = 2 kT (R_1 + R_2).$$

Two Resistance in Parallel

$$G_v(f) = 2 kTR = 2 kT \frac{R_1 R_2}{R_1 + R_2}.$$

Noise calculation

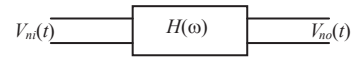


Fig. 10.13

$G_{ni}(\omega)$ = Input Spectral density

$G_{no}(\omega)$ = Output Spectral density

$$\text{Then } G_{no}(\omega) = |H(\omega)|^2 G_{ni}(\omega)$$

For series combination

$$G_{no}(\omega) = G_{n1}(\omega) + G_{n2}(\omega) = 2kT (R_1 + R_2)$$

Shot Noise

It is caused by random variations in the arrival of electrons (or holes) at the output electrode of an amplifying device and thus appears as a randomly varying noise current superimposed on the output. When amplified, it is supposed to sound as though a shower of lead shot were falling on a metal sheet; hence the name shot noise.

For a diode, the formula is exactly.

$$i_n = \sqrt{2ei_p \delta f}$$

where i_n = r.m.s. shot-noise current

Thus the noise current has been replaced by a resistance, so that it is now easier to add shot noise and the thermal noise. Furthermore, it has also been referred to the input of the amplifier, which is a much more convenient place.

The value of the equivalent shot noise more resistance R_{eq} of a device is generally quoted in the manufacturer's specifications.

$$R_{eq} \cong \frac{2.5}{g_m}.$$

Noise Figure

The signal to noise ratio at a point in a circuit is defined as ratio of signal power to noise power

$$\frac{S}{N} = \frac{P_s}{P_n} = \frac{V_s^2/R}{V_n^2/R} = \frac{V_s^2}{V_n^2}$$

This equation is applicable whenever the resistance across which noise is developed is same as the resistance across signal is developed.

To measure the performance of the system/receiver/amplifier a separate type of parametre measurement system is required that is known as **Noise figure**.

Noise figure F is defined as the ratio of signal to noise power supplied to input terminals of receiver, to signal to noise power supplied to the output or load resistance.

$$\begin{aligned} \therefore F &= \frac{S_i/N_i}{S_o/N_o}; S_o = A S_i \\ &= \frac{S_i}{N_i} \times \frac{N_o}{S_o} \end{aligned}$$

$$F = \frac{S_i}{N_i} \times \frac{N_o}{AS_i} = \frac{N_o}{AN_i}$$

$$F = \frac{N_o}{AN_i} = \frac{\text{Total Noise Power at load}}{\text{Amplified Noise Power due to source}}$$

$$\text{Also, } N_o = AN_i + N_s$$

$$F = \frac{AN_i + N_s}{AN_i}$$

$$F = 1 + \frac{N_s}{AN_i}$$

For ideal system, $N_s = 0$ i.e., system is not contributing any noise. $F_{min} = 1$.

In practical system, Noise N_s is finite.

In general $F \geq 1$

Lower the value of F , better is the performance of the system.

Noise figure is often referred to as noise factor. It is customary to express **Noise factor as number** and **Noise figure in db**.

$$Fdb = 10 \log_{10} F$$

Noise figure provide a means of specifying the deterioration in S/N ratio that is produced by the amplifier as result of the noise generated by the tubes and circuit of amplifier.

F For Cascaded Stage

$$F = F_1 + \frac{F_2 - 1}{A_{a1}} + \frac{F_3 - 1}{A_{a1}A_{a2}} + \frac{F_4 - 1}{A_{a1}A_{a2}A_{a3}} + \dots$$

This is known as **Friis's formula**.

Noise Temperature

The available noise power is proportional to temperature and is independent of resistance value. The noise power is specified in terms of temperature called the *Noise temperature*

$$F = 1 + \frac{N_s}{AN_i} = 1 + \frac{T_e}{T_o}$$

where, T_e is Equivalent noise temperature given by N_s ; T_o is room temperature i.e., $290^\circ K$

$$T_e = T_{e1} + \frac{T_{e2}}{A_{a1}} + \frac{T_{e3}}{A_{a1}A_{a2}} + \dots$$

Comparison on the basis of noise temperature is generally done among receiver, UHF and microwave low noise antenna, as comparison by noise figure is not convenient there.

Equivalent Noise Bandwidth

The noise Bandwidth is an important parametre for specifying the noise power at the output of BPF system.

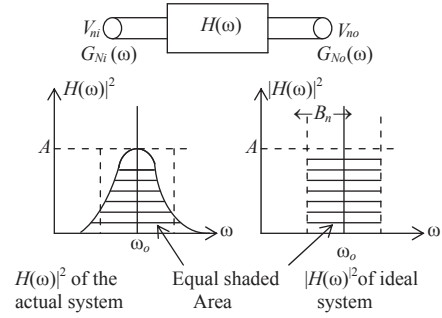


Fig. 10.14

$$\text{Area} = \int_0^\infty |H(\omega)|^2 d\omega$$

If the Area of Actual filter and ideal filter are equal with the height of both one equal then the Bandwidth of ideal system is called equivalent Bandwidth denoted by B_n .

$$A \times B_n = \int_0^\infty |H(\omega)|^2 d\omega ; B_n = \left(\frac{1}{A} \right) \int_0^\infty |H(\omega)|^2 d\omega$$

$$= \frac{\text{Area under the } |H(\omega)|^2 \text{ curve}}{\text{Max value of } |H(\omega)|^2 \text{ curve}}$$

Equivalent noise BW is the BW of the ideal Band-pass system which produces the same noise power as actual system.

10.2 ANALOG COMMUNICATION SYSTEMS

Modulation is a fundamental requisite of communication system. It is defined as the process by which some characteristics of signal called carrier is varied in accordance with the instantaneous value of another signal called modulating signal. Signals containing information or intelligence to be transmitted are referred to as modulating signals or base band signal frequency is greater than the modulating frequency. The signal resulting from the process of modulation is called modulated signal.

Analog (Continuous wave) Modulation

When the carrier wave is continuous in nature the modulation process is known as continuous wave (CW) modulation or analog modulation. The carrier wave is usually a sinusoidal signal.

Modulating signal $\rightarrow m(t)$ or $f(t) \rightarrow$ Audio signal 15 Hz – 15 kHz

Carrier signal $\rightarrow \sin \omega_c t$ or $\cos \omega_c t$

Advantage of Modulation

1. Using modulation; length of receiving antenna is relatively small.

- Using modulation S/N increases.
- At low frequency (Audio frequency) attenuation is large, i.e., propagation range is small, this range is increased using modulation at relatively higher frequency.
- Multiplexing.
- Narrow banding.
- Audio signal 20 Hz to 20 kHz, when transmitted as usual mix-up inseparably. Broadcasting station alone would blanket the air, very less number of channel can be used.
- Common processing (Tx and Rx).

Amplitude Modulation

Here the amplitude of the carrier is varied in accordance with the instantaneous value of the amplitude of the modulating signal. Keeping frequency and phase of the carrier to be fixed.

$$f(t) = v_m(t) = V_m \sin \omega_m(t) \rightarrow \text{mod. signal}$$

$$v_c(t) = V_c \sin \omega_c(t) \rightarrow \text{carrier}$$

Modulated Signal (AM Signal)

$$\begin{aligned} V(t) &= [V_c + K_a V_m(t)] \sin \omega_c t \\ &= V_c \sin \omega_c t + K_a V_m [2 \sin \omega_c t \sin \omega_m t] \\ &= V_c \sin \omega_c t + K_a \frac{V_m}{2} \left[\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t \right] \end{aligned}$$

Modulation Index ($m_a = 0.4$ to 0.6)

The extent of amplitude variation in AM about an un-modulated carrier amplitude is measured in terms of a factor called modulation index. It is define as:

$$m_a = \frac{V_m(\text{max})}{V_c} = \frac{K_a V_m}{V_c} = \frac{V_m}{V_c} \text{ (if } K_a = 1)$$

$$V_m = \frac{m_a V_c}{K_a} \text{ or } K_a V_m = m_a V_c$$

This factor m_a is also known as: (i) depth of modulation or (ii) degree of modulation or (iii) modulation factor.

Power Contained in the AM Signal

$$V(t) = V_c \sin \omega_c t + \frac{m_a V_c}{2} [\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t]$$

Power = $P_c \left(1 + \frac{m_a^2}{2} \right) \rightarrow$ Only for the sinusoidal type of modulating signal.

Efficiency of Transmission AM-DSB/FC

$$\eta = \frac{m_a^2}{2 + m_a^2}$$

$$\eta = 33.3\%$$

For *broadcasting* AM DSB/FC is always preferred since the receiver configuration is the simplest.

AM-DSB/SC Modulation

Modulation signal = $f(t)$

Carrier = $\cos \omega_c t$

Frequency components.

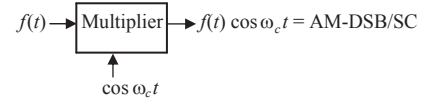


Fig. 10.15

$$\begin{aligned} f(t) \cos \omega_c t &= f(t) \frac{(e^{j\omega_c t} + e^{-j\omega_c t})}{2} \\ &= FT \left[\frac{1}{2} f(t) e^{j\omega_c t} \right] + FT \left[\frac{1}{2} f(t) e^{-j\omega_c t} \right] \\ &= (1/2) [F(\omega + \omega_c)] + F(\omega - \omega_c) \end{aligned}$$

AM-DSB/SC-Modulation

- Carrier undergoes a 180° phase reversal at zero crossings of $m(t)$.
- Modulation process simply shift the message spectrum by $\pm f_c$.
- Contains both upper side band as well as lower side bands.

AM-DSB/SC Demodulation Scheme

- This demodulation scheme is known as **coherent demodulation** because carrier with same frequency and phase is required to demodulate.

If constant phase difference is present between two inputs of a multiplier especially in the carrier part then $v(t)$ output will contain the term $m(t) \cdot \cos \phi$ where ϕ is the phase difference.

- This will be the output of LPF.

- If $\phi = \frac{\pi}{2}$ then output of LPF = 0

This is called quadrature Null effect.

- If constant frequency difference is present then output is proportional to $m(t) \cos(2\pi \Delta f t)$ Δf is frequency difference.

AM-DSB/SC Demodulation

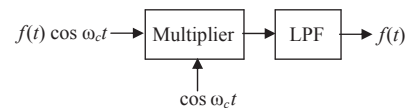


Fig. 10.16

After the multiplier

$$\begin{aligned}
 &= f(t) \cos^2 \omega_c t \\
 &= (1/2) f(t) [1 + \cos 2\omega_c t] \\
 &= (1/2) f(t) + (1/2) f(t) \cos 2\omega_c t
 \end{aligned}$$

After LPF

$(1/2)f(t)$ is passed and $(1/2)f(t) \cos 2\omega_c t$ is attenuated
 $\therefore f(t)$ is recovered

$$\begin{aligned}
 &f(t) \cos^2 \omega_c t \\
 &= (1/2) f(t) + (1/2) 2 \cos 2\omega_c t \\
 &= (1/2) F(\omega) + (1/4) [F(\omega + 2\omega_c) + F(\omega - 2\omega_c)]
 \end{aligned}$$

Carrier Recovery for Coherent Demodulation

Two methods

1. Costas loop
2. Squaring loop
 - Phase locked loop is used in this scheme. This is also for generating correct frequency equal to carrier frequency.
 - Squaring operating gives non-zero DC value.
 - Both costas loop and squaring loop have disadvantage of 180° phase ambiguity.

Addition of extra circuitry for generating coherent carrier increases the cost of receiver. To avoid that carrier should be present during transmission. This process is called doubled side band large carrier or Amplitude modulation.

AM-DSB/FC or (AM-DSB)

= AM SDB/SC + Carrier

$$V(t) = f(t) \cos \omega_c + \cos \omega_c$$

AM-DSB/SC carrier

$$V(t) = \cos \omega_c t + [A + f(t)]$$

where $A \rightarrow$ DC component

$$\begin{aligned}
 FAM(\omega) &= (1/2) [F(\omega + \omega_c) + F(\omega - \omega_c)] \\
 &+ \pi A [\delta(\omega + \omega_c) + \delta(\omega - \omega_c)]
 \end{aligned}$$

AM-DSB/FC

$$|K_a m(t)| \leq 1$$

$$|1 + K_a m(t)| \geq 0$$

If $[1 + K_a m(t)]$ is not non negative for all t , then envelope will be difference from $m(t)$.

$$|K_a m(t)|_{\max} = m_a \text{ modulation index}$$

if $|K_a m(t)|_{\max} > 1$ then we will have **over modulation** resulting in envelope distortion.

(i) $|A| \geq [f(t)]_{\max} \rightarrow$ Envelop detection

(ii) $|A| = [f(t)]_{\max} \rightarrow$ Synchronous detection.

Envelop Detection

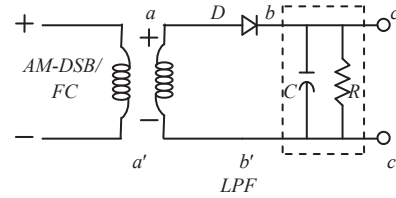


Fig. 10.17

Case 1: $T_2 = RC$ is large

Result *Diagonal Clipping*. It may occur due to higher modulating frequency.

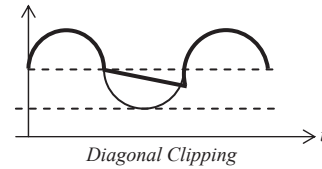


Fig. 10.18

Case 2:

$T_2 = RC$ is small. Result *Negative peak clipping*. It may be due to large modulation index.

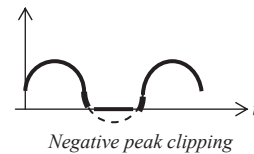


Fig. 10.19

Case 3: $T_2 = RC$ is medium

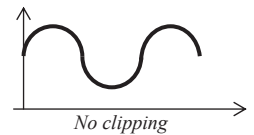


Fig. 10.20

The T_2 is adjusted so that exponential decay of capacitor voltage during discharge follows the envelope.

Discharge time constant RC should be such that the rate of capacitor discharge = Slope of envelope of modulated signal. Then the output capacitor voltage follows the envelope and $f(t)$ is detected with high S/N

$$\frac{1}{RC} \geq \frac{\omega_m m_a}{\sqrt{1 - m_a^2}} \rightarrow \text{for no clipping}$$

Typically $m_a = 0.4$, $m_a^2 = 0.16$

$$\frac{1}{RC} \geq m_a \omega_m$$

$$\frac{1}{RC} \geq 2\pi f_m m_a \rightarrow \text{approximately.}$$

$$\frac{1}{f_c} \leq R_L C \leq \frac{1}{f_m}$$

Representation of AM

$$V(t) = V_c \sin \omega_c t + \left(\frac{K_a V_m}{2} \right) \cos(\omega_c - \omega_m) t$$

$$- \left(\frac{K_a V_m}{2} \right) \cos(\omega_c + \omega_m) t$$

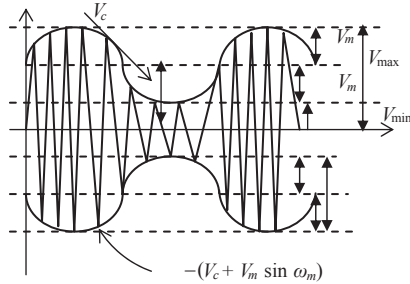


Fig. 10.21

$$V_m = \frac{V_{\max} - V_{\min}}{2}$$

$$V_c = V_{\max} - V_m = \frac{V_{\max} + V_{\min}}{2}$$

Modulation index

$$m_a = [V_m / V_a] = \frac{[(V_{\max} - V_{\min}) / 2]}{[(V_{\max} + V_{\min}) / 2]}$$

$$= \frac{[V_{\max} - V_{\min}]}{[V_{\max} + V_{\min}]}$$

Generation and Detection of AM-SSB/SC

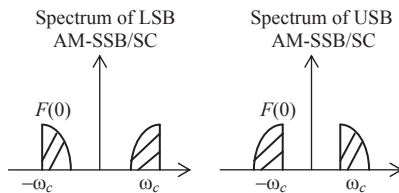


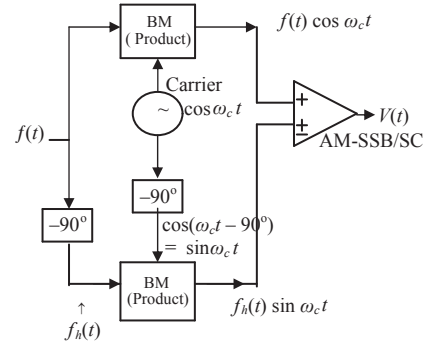
Fig. 10.22

There are three methods to Generate SSB/SC

1. The Filter System
2. Phase-Shift Method
3. The "Third" Method or Weaver Method.

Phase Shift Method of Generating

AM-SSB/SC Signal



Where $f_h(t)$ is the Hilbert transform of $f(t)$

Fig. 10.23

Special Case:

Let $f(t) = \cos \omega_m t$

→ It holds good for any general signal

$$\therefore V(t)|_{\text{SSB/SC}} = \cos \omega_m t \cdot \cos \omega_c t + \sin \omega_m t \cdot \sin \omega_c t$$

$$= \cos(\omega_c - \omega_m) t$$

= LSB is generated

$$V(t)|_{\text{SSB/SC}} = f(t) \cos \omega_c t + f_h(t) \sin \omega_c t$$

→ LSB is generated

$$= f(t) \cos \omega_c t - f_h(t) \sin \omega_c t$$

→ USB is generated

In general representation of AM.SSB/SC

$$V(t) = f(t) \cos \omega_c t \pm f_h(t) \sin \omega_c t.$$

Detection of AM-SSB/SC Signal

Therefore original modulating signal is recovered.

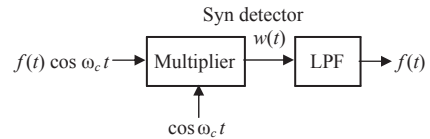


Fig. 10.24

Advantage of Phase Shift Method

1. Switching from one side band to other is simpler.
2. It is possible to generate SSB at any frequency.
3. SSB with lower Audio frequency can be generated.

Generation and Detection of AM-SSB/FC

$$V(t) = [f(t) \cos \omega_c t \pm f_h(t) \sin \omega_c t] + A \cos \omega_c t$$

AM SSB/SC

Generation is similar to AM-SSB/SC and then carrier is added.

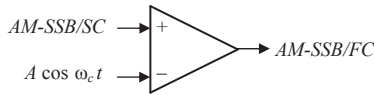


Fig. 10.25

Note: Video signal in television broadcast transmitted by AM-SSB/FC.

Detection of AM-SSB/FC

→ Envelop detection is done

Vestigial Sideband Transmission

→ Compromise between DSB and SSB.

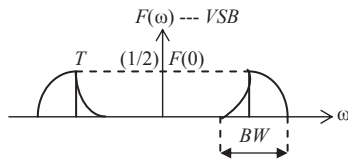


Fig. 10.26

Vestigial Sideband Modulation

DSB modulation, easy to generate but it requires more bandwidth.

SSB requires less bandwidth but difficult to generate. It is difficult to generate $\frac{\pi}{2}$ phase shifter over a 5 MHz bandwidth.

Sharp cut-off filter have highly non linear phase characteristic and this refer from phase distortion.

Phase distortion will be more prominent in picture rather then sound.

To overcome this vestigial sideband modulation comes into picture. In this required sideband is retained almost completely in addition a trace of unwanted sideband is added to the wanted sideband.

Note:

- DSB-SC, SSB and USB modulations are linear modulation in strict sense.
- AM is not linear in strict sense.

Angle Modulation

A general modulated carrier signal can be represented mathematically as

$$x_c(t) = A(t) \cos \omega_c t + \phi(t)$$

where, $A(t)$ and $\phi(t)$ are called the instantaneous amplitude and phase angle of the carrier.

When $A(t)$ is linearly related to the message signal $f(t)$ the result is amplitude modulation.

If $\phi(t)$ or its derivative is linearly related to $f(t)$, then we have *phase or frequency* i.e., (*angle*) modulation.

Let, modulating signal = $f(t)$

$$\text{Carrier} = A \cos \omega_c t = A \cos \theta(t)$$

For angle modulation, the modulated carrier is represented by

$$x_c(t) = A \cos \omega_c t + \phi(t)$$

where A and ω_c are constant and the phase angle $\phi(t)$ is function of the message signal $f(t)$. If we rewrite above equation

$$x_c(t) = A \cos \theta(t)$$

$$\text{where } \theta(t) = \omega_c t + \phi(t)$$

Then we can define the *instantaneous radian frequency* of $x_c(t)$ defined by ω_i as

$$\omega_i = \frac{d\theta(t)}{dt} = \omega_c + \frac{d\phi(t)}{dt} = \omega_c + \omega_\Delta$$

The function $\phi(t)$ and $[d\phi(t)/dt]$ are known as the instantaneous phase deviation and instantaneous frequency deviation of $x_c(t)$. The quantity $\Delta\omega = \delta$ defined by

$$\Delta\omega = |\omega_i - \omega_c|_{\max}$$

Is called the maximum (or peak) radian frequency deviation of the angle modulated signal

$$\text{where, } \theta(t) = \omega_c t + \phi(t) \quad \omega_c \rightarrow \text{frequency}$$

$$\frac{d\theta(t)}{dt} = \omega_c + \frac{d\phi(t)}{dt} ; \quad \phi(t) \rightarrow \text{Phase}$$

$$\theta(t) = \omega_c t + \frac{d\phi(t)}{dt} \quad \downarrow$$

FM: Frequency is varied with $f(t)$

$$\omega'_c = \omega_c + k_f f(t) \rightarrow \text{instantaneous frequency}$$

$$\omega'_c = \omega_c + \frac{d\phi(t)}{dt} \quad \downarrow$$

$$K_f f(t) = \frac{d\phi(t)}{dt} ; \quad \phi(t) = K_f f(t) dt$$

where K_f = the frequency deviation constant expressed in radian/sec for FM

$$\theta'(t) = \int \omega'_c dt = \int [\omega_c + K_f f(t)] dt$$

$$= \omega_c t + \frac{d\phi(t)}{dt} \quad \downarrow$$

$$\text{FM signal } f(t) = A \cos \theta'(t)$$

$$= A \cos \int [\omega_c + K_f f(t)] dt$$

$$f_{FM}(t) = A \cos \omega_c t + K_f \int f(t) dt$$

PM: The instantaneous phase deviation of the carrier is proportional to the message signal; that is

$$\phi(t) = K_p f(t)$$

$$\theta(t) = \omega_c t + \phi(t)$$

$$\theta'(t) = [\omega_c t + K_p f(t)]$$

$$\omega'_c = \omega_c + K_p \frac{df(t)}{dt} \rightarrow \text{instantaneous frequency}$$

where, K_p is the phase deviation constant expressed in radian/unit of $f(t)$ for PM.

$$\text{PM signal} = A \cos \theta'(t)$$

$$f_{PM}(t) = A \cos [\omega_c t + K_p f(t)]$$

$$f_{FM}(t) = A \cos \left[\omega_c t + K_p \int f(t) dt \right].$$

FM:

Note:

1. Average power in PM and FM signal is $\frac{A_c^2}{2}$. It depends only on carrier amplitude
2. PM and FM can be obtained from each other.

Relationship between PM and FM

PM and FM are closely related in the sense that the net effect of both is variation in total angle. In PM the phase angle varies linearly with $f(t)$ where as in FM phase angle varies linearly with the integral of $f(t)$.

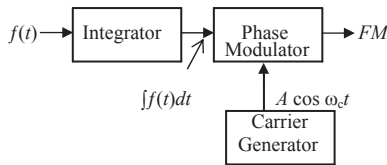


Fig. 10.27

Definition of Modulation Index

For FM deviation is proportion to modulating voltage

$$E_m, \text{ i.e., } [\Delta\omega = \delta] \propto E_m ; \left(\frac{\delta}{E_m} \right) = K_f$$

$$\delta = K_f \cdot E_m \text{ Hz}$$

$$\text{or } \delta = K_f \cdot E_m \text{ rad}$$

$$m_f \cdot \omega_m = \Delta\omega = \delta = K_f \cdot E_m$$

Definition of Modulation Index for FM

$$m_f = \frac{K_f \cdot E_m}{\omega_m}$$

For PM

$$m_p = (K_p \cdot E_m)$$

In general, modulation index β for angle modulation is defined as

$$\beta = \begin{cases} K_p E_m & \text{for PM} \\ \frac{K_f E_m}{\omega_m} & \text{for FM} \end{cases}$$

Relation Between Δ , f_m , M_f

$\delta \rightarrow$ Frequency deviation

$m_f \rightarrow$ Modulation index

$f_m \rightarrow$ Modulation frequency.

$$\delta = m_f \cdot f_m$$

In general angle modulation index is given by

$$\beta = \frac{\Delta\omega}{\omega_m}$$

Main Points:

1. In PM the angle is varied linearly with the modulating signal where as in FM the angle varies linearly with the integral of the modulating signal.
2. If we integrate the modulating signal $f(t)$ then Phase modulation it, we get FM signal.
3. If we differentiate $f(t)$ first and use it for Frequency modulation, the carrier we get the phase modulation signal.
4. PM and FM are inseparable since, any variation in phase of the carrier result in the variation in frequency and vice versa.
5. Relation between frequency deviation (δ), modulation index (m_f) and modulating frequency (f_m) is given by

$$\delta = m_f \cdot f_m \rightarrow \text{Hz}$$

$$\delta = m_f \cdot \omega_m \rightarrow \text{rad/sec.}$$

6. The frequency deviation controls the Bandwidth required to transmit FM signal
 $\delta \uparrow \rightarrow BW \uparrow$
7. The modulation index m_f controls the number of side Band to be included in FM signal.
 $m_f \uparrow \rightarrow \text{number of SB} \uparrow$
8. In contrast to AM where only 2SB are present, FM signal has infinite number of SB, Therefore ideal, Bandwidth required to transmit FM is infinite.
9. If the power contribution due to SB after a specified number is negligible, the BW is restricted to a finite value.

$$BW|_{FM} \cong 2(\delta + f_m)$$

This is known as Carson's rule

1. For a narrow Band FM, $m_f < 0.6$
2. For wide Band FM, $m_f > 0.6$
3. For angle modulation amplitude is always constant
4. The power of FM carrier is same as modulated carrier. By proper choice of m_f the efficiency of transmission can be raised to 100%.

Modulation Method

→ Direct modulation: Reactance modulator

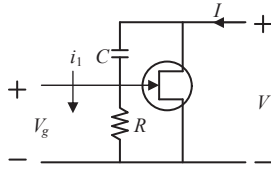


Fig. 10.28

$$Z_o = \frac{1}{j\omega C_{eq}}$$

where, $C_{eq} = g_m RC$.

Therefore, the output impedance of the given circuit is capacitive

If $X_c \gg R$

Let, $\left(\frac{X_c}{R}\right) = n$ and $(n \gg 1)$

$$Z_o = \frac{-jX_c}{g_m R} = \frac{1}{jg_m} \frac{X_c}{R}$$

$$Z_o = \left(\frac{n}{jg_m}\right);$$

$$C_{eq} = \left(\frac{g_m}{n\omega}\right).$$

Basic Principle of Reactance Modulator

1. The trans conductance g_m of FET varies w.r.t to the input voltage V_g or V_m

$$f = \frac{1}{2\pi\sqrt{LC}}.$$

2. The C_{eq} is connected effectively in parallel with a fixed frequency carrier oscillator. The frequency of carrier oscillator is given by

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where effect of C_{eq} is taken then

$$C' = C_{eq} + C_o.$$

Frequency at the output

$$= \frac{1}{2\pi\sqrt{[L_o(C_o + C_{eq})]}}.$$

3. Hence the frequency of the Carrier is effectively varied in accordance with the amplitude of input modulating signal $V_m = V_g$.
4. The result is a frequency modulated signal.

Indirect Method of FM

Armstrong method

FM Signal Range = 88 MHz to 108 MHz $\cong f_c$

Frequency deviation $\delta = \pm 75$ kHz

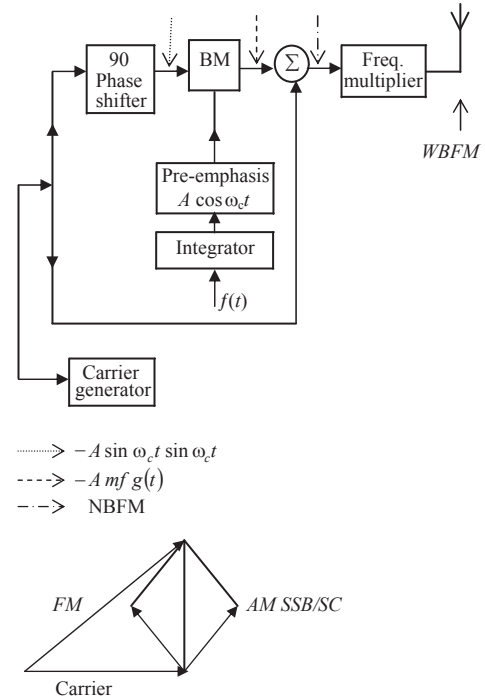


Fig. 10.29

Generation of narrow Band FM using Balance Modulator.

Narrow Band FM is multiplied than the result is multiplication of frequency and modulation index which result as a wide Band FM and known as

$$\phi_{FM}(t) = A \cos \omega_c t - A m_f g(t) \sin \omega_c t$$

$$\phi_{PM}(t) = A \cos \omega_c t - A m_f f(t) \sin \omega_c t.$$

Note: The expression for FM and PM are very much similar to the expression of AM signal, with only slight modification. Hence the narrowband FM is same as AM.

$$AM + NBFM \rightarrow SSB \text{ with carrier.}$$

Pre-Emphasis Circuit (HPF) and De-Emphasis Circuit [L P F]

Need of Pre-Emphasis Circuit

1. The modulating signal has a fundamental frequency + number of frequency harmonics.
2. At higher frequency amplitude of the modulating signal decreases.
3. The noise is uniformly distributed at all frequencies. Hence the S/N ratio decreases at higher frequencies relative to that at the lower frequencies.

- Therefore prior to transmission of signal, to increase S/N ratio at higher frequencies, we emphasize the high frequency components.
- A pre-emphasis circuit provide extra noise immunity by amplifying the higher audio frequency.
- To retain the same proportion of S/N ratio, we use de-emphasis circuit. The circuit will de-emphasize the frequency components at the same rate having the same cut off frequency as that of pre-emphasis.

Frequency Multiplier

- A frequency multiplier is a combination of nonlinear elements and BPF. It is used to increase the frequency deviation of FM signal.
- As the order of multiplication increases the output signal becomes progressively smaller. Thus multiplication factor 2 or 3 are used.
- The multiplier multiplies both carrier and frequency deviation, i.e., modulation index.
- A mixer, since it yields sum and difference frequency, will translate the spectrum of an FM signal, but will have no effect on its frequency deviation.

Disadvantage of Indirect method is the introduction of noise in the process of multiplication and distortion in the generation of NBFM signal.

FM Demodulators

The FM detector performs the extraction of modulating signal in two steps:

- It converts the frequency modulated signal into a corresponding AM signal by using frequency dependent circuit, i.e., circuits whose output voltage depends on input frequency. Such circuit is called as *frequency discriminator*.
- The original modulating signal $f(t)$ is recovered from this AM signal by using a linear diode envelop detector.

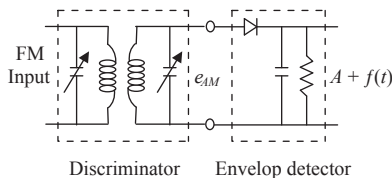


Fig. 10.30

Demodulation of FM

1. FM to AM conversion

The instantaneous frequency of an FM signal is given by $f_i = f_c + K_f m(t)$. Hence frequency selective network with a transfer function of the form $|H(f)| = af + b$, where a and b are constants, would yield an output proportional to $m(t)$, the message signal.

Here time constant of the network should be small enough in comparison with the variation in instantaneous frequency of FM signal.

2. Phase shift discriminator

This method involves converting frequency variations into phase variations and detecting the phase changes.

Foster seeley discriminator, ratio detector and quadrate detector.

3. Zero Crossing detection

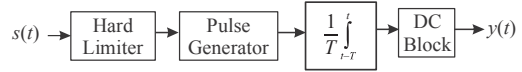


Fig. 10.31

When the input to hard limiter is an FM signal, the hard limiter output appears as a square wave of varying frequency. This hard limiter output triggers a monostable pulse generator which produces a short pulse of amplitude A and duration τ at each upward or downward transmission.

These pulses on averaging and DC block gives an output proportional to message signal, $m(t)$.

4. FM demodulation using PLL

Block diagram of PLL

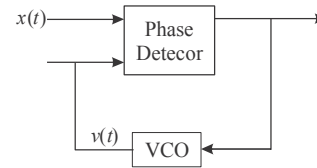


Fig. 10.32

The basic aim of a PLL is to lock the instantaneous angle of a VCO output to the instantaneous angle of a signal that is given as input to the PLL.

Advantage of Foster-Seeley

- Much easier Alignment
- Better linearity
- Fewer tuned circuit.

Advantage of Slope Detector

- Greater limiting.

Disadvantage

- Transmitter and receiver circuits are complex.
- Limited range, i.e., range limited to line of sight (LOS) communication.
- Bandwidth is large.

Frequency Spectrum of FM Wave

Let, $f(t) = V_m \cos \omega_m t$

carrier $= A \sin \omega_c t$

$$f_{FM}(t) = A \cos \left(\omega_c t + m_f \int f(t) dt \right)$$

$$f_{FM}(t) = A \sin \left(\omega_c t + m_f \sin \omega_m t \right)$$

- it is sin of a sin function
 → the solution for this function involve the use of Bessel function.

$$\begin{aligned}
 f_{FM}(t) &= A \sin(\omega_c t + m_f \sin \omega_m t) \\
 &= A J_0(m_f) \sin \omega_c t \\
 &+ J_1(m_f) \left([\sin \omega_c t + \omega_m] t - \sin(\omega_c - \omega_m) t \right) \\
 &+ J_2(m_f) \left([\sin \omega_c t + 2\omega_m] t - \sin(\omega_c - \omega_m) t \right) \dots
 \end{aligned}$$

It is seen that the output consist of a carrier and apparently infinite sidebands each preceded by J coefficient. These are Bessel function.

Main Points

1. Unlike AM where there are only three frequencies, FM has an infinite number of sidebands.
2. The J coefficient eventually decreases in value as n increases but not in any manner.
The modulation index thus determines how many sideband components have significant amplitude.
3. The sidebands at equal distances from f_c have equal amplitudes.
4. In AM increased depth of modulation increases the sideband power and therefore the total transmitted power.
In FM the total transmitted power always remains constant but with increased depth of modulation, the required sideband is increased.

10.3 SUPER HETERODYNE RECEIVER

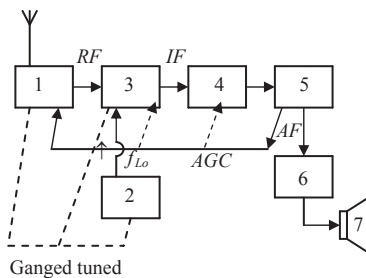


Fig. 10.33

Block Name

1. RF amplifier
 2. Local oscillator: $f_{Lo} = RF + IF$
 3. Mixer
 4. IF amplifier stage
 5. Detector
 6. AF amplifier
 7. Loud Speaker.
- In the super heterodyne receiver, the signal (RF) voltage is combine with the local oscillator (f_{Lo}) voltage and normally converted to lower fixed frequency (IF). The signal at intermediate frequency (IF) contains the same

modulation as the original carrier and is now amplifier and detected to reproduce the original information. A constant frequency difference ($IF = f_{Lo} - F$) is maintained between local oscillator and the RF circuit, normally through capacitor tuning in which all the capacitors are ganged together and operate by one control knob.

- Maximum amplification of signal takes place at the IF stage. This stage is independent of the received tuned frequency.
- The RF circuit are used to select wanted frequency, to reject interference such as image frequency to reduce the noise figure of the receiver ($F \geq 1$).
- The advantage of the super heterodyne receiver make it the most suitable type for the great majority of radio receiver application; AM, FM, SSB, television and radar receiver with only slight modification.

Receiver Quality Factor

1. Sensitivity:

- The sensitivity of a radio receiver is its ability to amplify weak signals. It is often defined in terms of the voltage that must be applied to the receiver input terminals to give a standard output power, measured at the output terminals.
- The most important factors determining the sensitivity of a superheterodyne receiver are the gain of the IF amplifier(s) and that of the RF amplifier.

2. Selectivity:

- The selectivity of a receiver is its ability to reject (adjacent) unwanted signals.

3. Image Frequency Rejection:

- In a receiver the local oscillator frequency is made higher than the incoming signal frequency made equal at all times to the signal frequency plus the intermediate frequency. Thus, $f_{Lo} = f_s + f_i$ or $f_s = f_{Lo} - f_i$ no matter what the signal frequency may be.
- If a frequency f_{si} manages to reach the mixer, such that $f_{si} = f_{Lo} + f_i$ that is $f_{si} = f_s + 2f_i$ then this frequency will also produce f_i when mixed with f_{Lo} . Unfortunately, this spurious intermediate frequency signal will also be amplified by.

It is the IF stage and will therefore provide interference. This has the effect of two stations being received simultaneously and is naturally undesirable. The term f_{si} is called the *image frequency* and is defined as the signal frequency plus twice the intermediate frequency.

$$f_{si} = f_s + 2f_i$$

The *rejection of an image frequency* by a signal-tuned circuit, i.e., the ratio of at the gain at the signal frequency to the gain at the image frequency, is given by

$$\alpha = \sqrt{1 + Q^2 r^2}$$

$$\text{where, } \rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}}$$

Q = loaded Q of tuned circuit.

Image rejection depends on the front-end selectivity of the receiver and must be achieved before the *IF* stage. Once the spurious frequency enters the first *IF* amplifier, it becomes impossible to remove it from the wanted signal.

4. Fidelity:

- It is the variation of the output with modulation frequency when the output load impedance is a resistance.
- Reproduction of original modulating signal in respect to amplitude and frequency.

5. Noise figure:

- Noise figure is defined as the ratio of signal to noise power supplied to input terminals of receiver, to signal noise power supplied to the output or load resistance.
- $$F = \frac{S_i/N}{S_o/N_i}$$
- Noise figure is measured to check the performance of the receiver.

10.4 REALIZATIONS OF ANALOG COMMUNICATION SYSTEMS

Noise in Modulation System

Noise in AM System

A band-pass random noise $n(t)$

$[BW = 2\omega_m]$ can be expressed as

$$n(t) = n_c(t) \cos \omega_c t + n_s(t) \sin \omega_c t$$

where, $n_c(t)$ = In phase component and

$n_s(t)$ = Quadrature component

of low pass noise $[BW = \omega_m]$.

The mean square are identical

$$\overline{n^2(t)} = \overline{n_c^2(t)} = \overline{n_s^2(t)}.$$

AM-DSB/SC

$$y(t) = \left[\frac{f(t)}{2} \right] + \left[\frac{n_c(t)}{2} \right] \quad (3)$$

Equation (3) indicate the following:

1. The message signal $f(t)$ and in-phase noise component $n_c(t)$ of the filtered noise $n(t)$ appear additively at the receiver output.
2. The Quadrature component $n_s(t)$ of the noise $n(t)$ is completely rejected by the coherent detector.

The figure of merit or improvement factor (*IF*) = (*S/N*) be summarized as follows:

$$\gamma = \frac{\frac{1}{2} \overline{f^2(t)}}{\frac{1}{2} \overline{1 + f^2(t)}} \quad \begin{array}{l} \text{SSB - SC} \\ \text{DSB - SC} \\ \text{AM - DSB/FC} \end{array}$$

$$\frac{m_a^2}{2 + m_a^2} \quad \text{DSB with sinusoidal modulation}$$

For Double sideband with sinusoidal modulation if modulation index $m_a = 100\% = 1$ then $\gamma_{AM} = [1/3]$.

Noise in FM

$$\text{If } \beta = [3/2] \beta^2$$

We conclude that

$$\frac{\gamma_{FM}}{\gamma_{AM}} = \frac{9}{2} \beta^2; \quad \frac{\gamma_{FM}}{\gamma_{AM}} = \frac{9}{2} \left(\frac{B_{FM}}{B_{AM}} \right)^2.$$

Comparison of Modulation System

1. For low (*S/N*) ratio SSB/SC is superior. For high (*S/N*), FM have some advantage but at the cost of more Bandwidth.
2. If received (*S/N*) is large, then PCM of more pulse/code should be used for max (*S/N*) ratio.
3. For option equipment simplicity factor DSB is the best.

Noise in PCM

The Average signal power is given by

$$S_i = (A^2/2)$$

where $A = K\sigma_n$

where σ_n Noise.

Mean square value of noise

$$N_i = \sigma_n^2$$

$$\text{Therefore } \left(\frac{S_i}{N_i} \right) = \frac{K^2}{2}.$$

Quantization Noise

The mean square Quantization error = e_k^2

$$\text{Quantization error} = \overline{e_k^2} = \frac{S^2}{12} = N_o$$

The mean square value of $f(t)$ is

$$S_o = \overline{f'^2(s)} = \frac{S^2}{12} M^2$$

$$\frac{S_o}{N_o} = \frac{S^2/12}{S^2/12} M^2 = M^2 = 2^n$$

$$= (2^n)^2 \quad \text{where } n = \text{number of bits/sample}$$

$$= 2^{(2n)}$$

$$\text{Improvement factor}(IF) = \frac{S_o/N_o}{S_i/N_i} = \frac{M^2}{k^2}.$$

10.5 FUNDAMENTALS OF INFORMATION THEORY AND CHANNEL CAPACITY THEOREM

Measure of information of a message state based on the probability of that message state's occurring i.e., Information received in transmitting a particular digit depends upon the probability with which it occurs.

Lower the probability of occurrence of given digit, higher is the information received.

Let, any digit = x_k

Probability with each occurrence = $P(x_k)$

Information received in Transmitting the digit is

$$\begin{aligned} I(x_k) &= \log \left(\frac{1}{P(x_k)} \right) \\ &= -\log_{10} P(x_k) \rightarrow \text{Hartley or decimal bit} \\ &= -\log_e P(x_k) \rightarrow \text{nats or nat} \\ &= -\log_2 P(x_k) \rightarrow \text{bits} \end{aligned}$$

$$\log_x Y = \frac{\log_{10}^Y}{\log_{10}^X} \rightarrow \text{Base change formula}$$

Hartley = $0.3 \times \text{bits}$

Bits = $1.44 \times \text{nats}$.

Basic Definition

1. Information received in transmitting any digit

$$I(x_k) = -\log_2 P(x_k) \rightarrow \text{bit}.$$

2. Average information received (Entropy)

$H(x)$ = Entropy of the source

$$H = -\sum_{i=1}^m P(i) \log P(i) \rightarrow \text{bits/symbol}$$



Fig. 10.34

where, m = total number of digits in one complete symbol.

Redundancy

A sequence of symbols which are dependent upon one another are termed as redundant. We measure the redundancy of a sequence of symbol by noting the amount by which the entropy has been reduced.

The redundancy is defined as

$$E = 1 - \frac{H(Y/X)}{H(X)}$$

where, E = Redundancy of message

$H(y/x)$ = The entropy of the message when inter symbol influence are taken into account

$H(x)$ = entropy assuming all symbols are independent.

1. Joint entropy

$$H(x, y) = -\sum_{i=1}^m \sum_{j=1}^n P(i, j) \log P(i, j) \rightarrow \text{bits/symbol}$$

2. Condition entropy

$$H\left(\frac{y}{x}\right) = -\sum_{i=1}^m \sum_{j=1}^n P(i, j) \log P\left(\frac{j}{i}\right) \rightarrow \text{bits/symbol}.$$

Properties of Entropy $H(X)$

- (a) If at the input only one digit is present.

$\therefore$ Probability of that digit = 1

$$H(x) = -\sum_{i=1}^1 P(i) \log P(i) = 1 \log 1 = 0$$

$H(x) = 0$ ---- No information received

- (b) If all the digit are occurring with equal probability.

$$P(i) = 1/m$$

$$H(x) = -\sum_{i=1}^m P(i) \log P(i)$$

$$= -\sum_{i=1}^m \left(\frac{1}{m} \right) \log \left(\frac{1}{m} \right) = -\log \left(\frac{1}{m} \right)$$

$$= -[\log 1 - \log m] = \log m$$

It is seen that this $H(x)$ is always max

$$H(x)_{\max} = \log_2 m \rightarrow \text{bits/symbols}$$

where, m = total number of bits in one symbol.

Mutual Information

The mutual information $I(x, y)$ of a channel is defined by

$$I(x, y) = H(x) - H\left(\frac{x}{y}\right) \text{ bit/symbol}.$$

Where $H(x)$ represents the uncertainty about the channel input before the channel output is observed and $H(x/y)$ represents are uncertainty about the channel input after the channel output is observed.

For a binary output is channel.

$$I(x, y) = H(y) + p \log_2 p + (1 - p) \log_2 (1 - p)$$

Binary Symmetric Channel

The binary symmetric channel (BSC) is defined by the channel diagram shown in Figure and its channel matrix is given by

$$[P(Y|X)] = \begin{bmatrix} 1-p & p \\ p & 1-p \end{bmatrix}$$

The channel has two inputs ($x_1 = 0, x_2 = 1$) and two outputs ($y_1 = 0, y_2 = 1$). The channel is symmetric because the probability of receiving a 1 if 0 is sent is the same as the probability of receiving a 0 if 1 is sent. This common transition probability is denoted by p .

For Symmetric Channel

1. $H(x) = H(y)$
2. $(x/y) = H(y/x)$.

Symbol Rate, Bit Rate and Information Rate

$H(x)$ = bits/symbol (entropy) → **Bit rate**

Let, s = Symbol being transmitted per second
= Symbol/second → **Symbol rate**

$H'(x)$ = Bits/second → **Information rate**

$$\therefore H'(x) = s H(x)$$

This $H'(x)$ is known as **information rate**.

Channel CAPACITY

Amount of information/second max bits/sec transmitted through a communication channel define channel capacity.

⇒ Number of bits that can be transmitted through a channel per second

Channel Capacity of Noiseless Discreet**Channel**

$$\begin{aligned} \text{Channel capacity } C &= \max [\text{Information rate}] \\ &= \max [H'(x)] \\ &= \max [s \cdot H(x)] \\ &= s H(x)_{\max} \\ C &= s \log_2 m \text{ --- bits/second} \end{aligned}$$

where m = Number of bits in one symbol.

Coding

Coding offers the most significant application of the information theory. The main purpose of coding is to improve the efficiency of the communication system in some sense. However, in this chapter we will study only the one-to-one codes, which (i) improve some sort of transmission efficiency and (ii) reduce probability of error by detecting and correcting errors.

Coding Efficiency

Let M be the number of symbols in an encoding alphabet. Let there be N messages $[m_1, m_2 \dots m_N]$ with the probabilities $[P_{(m1)}, P_{(m2)} \dots P_{(mN)}]$. Let n_i be the number of symbols in the i th message. The average length of the message or the average length per code word is then given by

$$\bar{L} = \sum_{i=1}^N n_i p(n_i) \text{ letters/message}$$

$\bar{L}$ should be minimum to have an efficient transmission. Coding efficiency, then, can be defined as

$$\eta = \frac{\bar{L}_{\min}}{L}$$

Now, let, $H(x)$ be the entropy of the source in bits/message. Also, let $\log M$ be the maximum average information associated with each letter in bits/letter.

Hence,

$$\text{The ratio } \frac{H(x)}{\log M} \text{ having a unit } \frac{\text{bits/message}}{\text{bits/letter}}$$

or letters/message, gives the minimum average number of letters per message.

$$\text{or } \frac{H(x)}{\log M} = \bar{L}_{\min}$$

Hence, the coding efficiency is

$$\eta = \frac{\bar{L}_{\min}}{L} = \frac{H(x)}{L \log M}, \text{ and redundancy} = 1 - \eta$$

Fano's coding

Fano has suggested a procedure for the construction of efficient code which tends to eliminate some of the guess work. If message of N symbol is arranged in a order of decreasing probability divided into two groups of as nearly equal probabilities as possible, then the division determines the first binary digit of code. Each group is then divided into subgroup with as nearly equal probabilities as possible which determines the second digit of the code group. This procedure is then continued until each sub group contain only one digit.

Consider the eight messages with probabilities given below and apply **Fano's coding**.

Huffman Encoding

In general, Huffman encoding method

Leads to the lowest possible value of the average length per code word i.e., $\bar{L}$ or a given M , results in minimum redundancy code or an **optimum code**. Thus it is the code that has the highest efficiency. The Huffman encoding procedure is as follows:

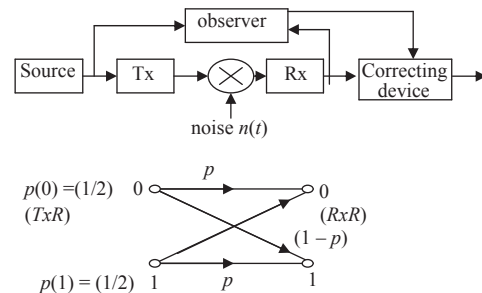
Discrete Noisy Channel

Fig. 10.35

Rate at which information is supplied by the channel to the receiver is given by

$$R = H'(x) = H'(x/y) \rightarrow \text{General}$$

10.20 ■ Communication Systems

If channel is symmetrical then $H(x/y) = H(y/x)$

Then $R = H'(x) = H'(y/x)$

Channel Capacity C = Max rate at which information is transmitted

$$= \max H'(x) - H'(x/y)$$

$$C = s \log_2 m - H'(x/y) \text{ bits/sec.}$$

Note: Channel capacity $C = 2W \log_2 N$

Continuous Channel

If the transmitted output is not a set of discrete message, rather it is a continuous signal, then the channel is a continuous one i.e., AM, FM, PM signal.

Noisy Channel

Case 1: For energy signal [Pulse signal] the entropy is maximum when the probability density function $p(x)$ is uniform.

Case 2: For power signal [periodic].

The entropy is maximum when the probability density function is Gaussian with zero mean.

Relation between Channel Capacity and S/N Ratio of Continuous Channel

Capacity of a Gaussian channel: Shannon's Hartley theorem.

$$C = W \log_2 \left(1 + \frac{S}{N} \right) \rightarrow \text{bit/sec}$$

It indicates that we may trade off bandwidth for S/N ratio and vice versa.

Limit on Channel Capacity as BW $\rightarrow$ Infinite

$$C = \frac{S}{G_o} \log \left[\lim_{[S/G_o B] \rightarrow 0} \left(1 + \frac{S}{G_o B} \right)^{\frac{1}{(S/G_o B)}} \right]$$

$$\frac{S}{G_o} \ln e = \frac{S}{G_e} \rightarrow \text{nates/sec}$$

$$C = 1.44 \frac{S}{G_o} \rightarrow \text{bits/sec}$$

Relation between input and output S/N

Channel $BW = W$ Message $BW = f_m$



Fig. 10.36

$$\left(\frac{S_o}{N_o} \right) = \left(\frac{S_i}{N_i} \right)^{W/f_m}$$

This is the relation between the input output SNR i.e., Maximum possible exchange between input and output of SNR.

10.6 DIGITAL COMMUNICATION SYSTEM

If only two values are allowed for the modulated parameter and if separation between these parameters is large as compared to noise disturbances. It is simple matter to decide which specific value are intended. Thus the effect of Random noise can be virtually eliminated. Which is the whole idea of **Pulse code modulation (Digital modulation)**.

Basic Principle of PCM

The essential processes of PCM are sampling, quantizing and encoding as shown in Figure.

The sampled signal $m_{ns}(t)$ can be written as

$$m_s(t) = m(t) p(t)$$

where $p(t)$ is the periodic train of rectangular pulse with period T_s , and each rectangular pulse in $p(t)$ has width $|t_d|$ and unit amplitude.

The sampling $m_{ns}(t)$ here is termed natural sampling, since the top of each pulse in $m_{ns}(t)$ retains the shape of its corresponding analog segment during the pulse interval. The effect of the finite width of the sampling pulses is investigated later on.

Flat-Top Sampling

The simplest and thus most popular practical sampling method is actually performed by a functional block termed the sample-and-hold (S/H) circuit [see figure]. This circuit produces a flat-top sample signal $m_s(t)$ [figure].

A flat topped pulse has a constant amplitude established by the sample value of the signal at some point within the electronic circuit used to perform the sampling operation.

Due to flat top sampling distortion results from the fact that the original signal was observed through a finite rather than an infinite signal time aperture and hence referred to as **aperture effect distortion**.

The distortion becomes progressively smaller with decreasing the pulse width $|t_w|$ and of course as $t_w \rightarrow 0$, the distortion approaches zero.

Loss of high frequency content is called **aperture effect**. The larger the pulse duration, the larger is the effect.

Uniform Quantizing

We assume that the amplitude of $m(t)$ is confined to the range $(-m_p, m_p)$. This range is divided in L .

Zones, each of step size $(\Delta = s)$ given by

$$\Delta = \frac{2m_p}{L} \quad (1)$$

where $s = \Delta$ and $L = M$.

A sample amplitude value is approximated by the midpoint of the interval in which it lies.

Quantizing Noise

The difference between the input and output signals of the quantizer becomes the quantizing error, or quantizing noise. It is apparent that with a random input signal, the quantizing error q_e varies randomly within the interval ($s = \Delta$)

$$\frac{-\Delta}{2} \leq q_e \leq \frac{\Delta}{2} \quad (2)$$

Assuming that the error is equally likely to lie anywhere in the range $(-\Delta/2, \Delta/2)$, the mean-square quantizing error (q_e^2) is given by

$$q_e^2 = 1 \int_{-\Delta/2}^{\Delta/2} q_e^2 dq_e = \frac{\Delta^2}{12} \quad (3)$$

$$\begin{aligned} \left(\frac{S}{N_q} \right)_0 dB &= 10 \log \left(\frac{S}{N_q} \right)_0 = 1.76 + 20 \log L \\ &= 1.76 + 20 \log 2^n [L = 2^n] \\ &= 1.76 + 6.02ndB \end{aligned}$$

where $L = M$ is the number of Quantizing levels.

Above equation indicates that each bit in the code word of a binary PCM system contributes 6 dB to the output signal-to-Quantizing ratio. This is called the **6 dB rule**.

Reception of PCM Signal

$S/N \cong 2^{2n}$ where n = number of bits sample

If $[n = 3]: (S/N) = 2^{2(3)} = 2^6 = 64$

$BW = (1/2) [\text{Bit rate}]$

$= (1/2) [nf_s]; f_s = 2f_m$

Quantization error $= (\Delta^2/12)$ where, Δ = step size

Number of steps $= 2^n$ = number of levels $= M$

$S/N = 2^{2n} = (2^n)^2 = M^2$

$\therefore M = 2^n$

$S/N = M^2$

If total range of input $\pm V$

the step-size $S = \frac{2V}{2^n} = \frac{2V}{M}$

if $n \rightarrow S/N \uparrow$

$\rightarrow BW \uparrow$

$\rightarrow$ Design of quantizer becomes complex

$\rightarrow$ Quantization error $\downarrow$.

Non-uniform Quantizing and Companding

A particular form of compression law that is used in practice (in North America and Japan) is the so-called μ law, defined by

$$y = \frac{\ell n \left(1 + \frac{\mu |m|}{m_p} \right)}{\ell n (1 + \mu)} \text{sgn}(m); \left| \frac{m}{m_p} \right| \leq 1$$

where μ is a positive constant and

$$\text{sgn}(m) = \begin{cases} +1 & m > 0 \\ 1 & m < 0 \end{cases}$$

$$\text{or } |V| = \frac{\log(1 + \mu |m|)}{\log(1 + \mu)}$$

where m and V the normalized input & output voltage and μ is positive complex.

The μ -law is neither strictly linear nor strictly logarithmic, but it is approximately linear at low input level corresponding to $\mu |m| \ll 1$, and approximately logarithmic at high input levels corresponding to $\mu |m| \gg 1$.

Another compression law that is used in practice (in Europe) is the so-called **A law**, defined by

$$y = \begin{cases} \frac{A}{1 + \ell n A} \left(\frac{m}{m_p} \right) & 0 \leq \left| \frac{m}{m_p} \right| \leq \frac{1}{A} \\ \left(\frac{1 + \ell n \frac{A|m|}{m_p}}{1 + \ell n A} \right) \text{sgn}(m) & \frac{1}{A} \leq \left| \frac{m}{m_p} \right| \leq 1 \end{cases}$$

For the μ law, $\mu = 255$ is used in digital telephone systems in North America. For the **A law**, $A = 87.6$ is used in European system.

To restore the signal samples to their correct relative level, an expander with a characteristic complementary to that of the compressor is used in the receiver. The combination of compression and expansion is called **companding**.

Compressing

1. For small input voltage level the signal strength is small, so that the signal power is small.
2. Since the noise is informally distributed noise power is relatively same at all different voltage levels.
3. Therefore for small signal level the S/N ratio is small relative to that at higher voltage level. Therefore Prior to transmission the PCM signal we compress. The higher voltage level relative to lower + voltage level.
4. This is done by the use of compressor.
5. At the receiver in order to maintain the same relative S/N ratio we use the expanding technique where we expand the higher voltage level relative to smaller one.

Bandwidth Requirements of PCM

$$2f_{PCM} = nf_s$$

$$\text{or, } f_{PCM} = \frac{nf_s}{2} \geq n f_m \text{ Hz.}$$

1. A PCM system has very high S/N ratio but at the cost of complex circuit. Specially the design of quantizer is most complexed.
2. To reduce the complexity of the circuit and still maintain same S/N ratio, we use another coded modulation called *delta modulation*.

Delta Modulation

A method for conversing analog to a string of binary digits that requires much simpler circuitry than PCM is delta modulation.

In the present case we used to know only weather $m(t)$ is large than $m^1(t)$ and not the magnitude.

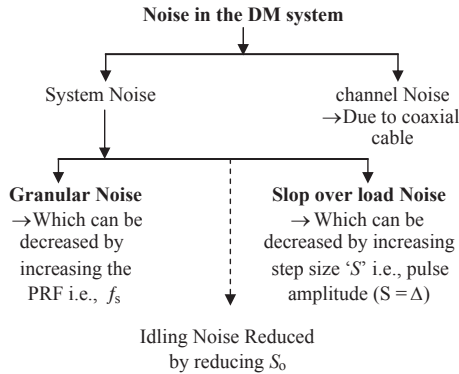


Fig. 10.37

Demodulation

Demodulation of DM is accomplished by **integrating** $m_{DM}(t)$ to form the staircase approximation $m'(t)$ and then passing through a low pass filter to eliminate the discrete jumps in $m'(t)$

Small step size is desirable to reproduce the input waveform accurately. However, small step size must be accompanied by a fast sampling rate to avoid slope overload, as shown in figure. **To avoid slope overload, we require that**

$$\frac{\Delta}{T_s} > \left| \frac{dm(t)}{dt} \right|_{\max}$$

Quantizing Error of DM

We assume that the Quantizing error in DM is equally likely to lie anywhere in the interval $(-\Delta, \Delta)$, so that the mean-square Quantizing error is

$$\langle q_e^2 \rangle = \frac{1}{2\Delta} \int_{-\Delta}^{\Delta} q_e^2 dq_e = \frac{\Delta^2}{3}$$

$$(\Delta = S).$$

To Minimize the Slop Over Load Noise

Let, $m(t) = A \sin \omega_m t \rightarrow$ modulating signal

$$2\pi f_m A \leq S f_s$$

$$A \leq \frac{S f_s}{2\pi f_m} \rightarrow \text{max high to modulating signal}$$

$$P_{\max} = A^2 = \frac{\Delta^2 f_s^2}{8\pi f_m^2} = S_o$$

where, f_M is the cutoff frequency of a low-pass filter at the output end of the receiver and the bandwidth of a post-reconstruction low pass filter at the output end of the receiver be $F_m \geq f_m$ and $F_M \ll f_s$

$$N_q = \left(\frac{\Delta^2}{3} \right) \frac{f_m}{f_s}$$

Combining the above two equations, we see that the Maximum Output Signal-to-Noise is

$$\left(\frac{S}{N_q} \right)_0 = P_{\max} = \frac{3f_s^3}{8\pi^2 f_m^2 f_M}$$

Adaptive Delta Modulation

Step size is not fixed but it is always a multiple of basic step. Which reduce slop over load Node

Inter-Symbol Interference

Pulse shaping and intersymbol interference (ISI)

Practically, channels have a limited bandwidth, and hence transmitted pulses tend to be “spread” during transmission, which causes overlap of pulses, and this phenomenon is known as ISI.

Pulse Shaping

A method of controlling ISI is to shape the transmitted pulses properly. A pulse shape that gives zero ISI is:

$$h(t) = \frac{1}{T_s} \frac{\sin\left(\frac{\pi t}{T_s}\right)}{\frac{\pi t}{T_s}}$$

This is the impulse response of an ideal LPF.

However, it is difficult to realize this filter shape. Hence, another method which reduces ISI is using Raised-Cosine filter.

$$H(\omega) = \begin{cases} 1, & 0 \leq |\omega| \leq (1-\alpha)W \\ \frac{1}{2} \left\{ 1 - \sin \left[\frac{\pi}{2\alpha W} (|\omega| - W) \right] \right\}, & (1-\alpha)W \leq |\omega| \leq (1+\alpha)W \\ 0, & |\omega| \leq (1+\alpha)W \end{cases}$$

Where $W = \pi T_s$.

The corresponding impulse response is:

$$h(t) = \frac{1}{T_s} \left(\frac{\sin Wt}{Wt} \right) \left[\frac{\cos \alpha Wt}{1 - \left(\frac{2\alpha Wt}{\pi} \right)^2} \right]$$

α is called the **roll-off factor**. If the desired pulse transmission rate is $\frac{1}{T}$ pulses/sec, the bandwidth f_B is: $f_B = \frac{1+\alpha}{2T}$ Hz

Eye Pattern

We can get a good quantitative indication of the performance of a PCM system by examining the stream on a C.R.O. The time base of CRO is set so that it trigger at the bit rate and yields a sweep last positive time slot duration.

- No Noise $\rightarrow$ eye open
- Less Noise $\rightarrow$ eye partial closed
- More distortion. $\rightarrow$ eye fully close

The addition of noise to the bit stream would close the eye still further.

Thus eye pattern of PCM system gives information regarding noise & Band width.

Comparison of PCM and DM. System

- The circuit required for PCM system is complexed specially the design of quantizer is most difficult.
In delta modulation system circuit required is very simple specially the demodulator.
- In PCM, $BW = (1/2) n f_s$
in DM, BW depend on f_s i.e., $f_s > n f_s$
Therefore BW required to transmit a signal using PCM system is less then that of DM.
DM: $BW = 100$ KHz
PCM: $BW = 64$ KHz (For same quality of reception).
- The error probability in the case of PCM system is small, so that the S/N ratio of PCM system is greater than that of DM system.

10.7 DIGITAL COMMUNICATION MODULATION SCHEMES

Because of base-band signals (PCM i.e., 1 and 0) have sizable power at low frequencies, they are suitable for transmission over a pair of wires or coaxial cable. Base-band (PCM) digital signals cannot be transmitted over a radio link because this would require impractically larger antennas to efficiently radiate the low-frequency spectrum of the signal.

Amplitude-Shift Keying (ASK)

In ASK, the modulated signal can be expressed as

$$x_c(t) = \begin{cases} A \cos \omega_o t & \text{symbol 1} \\ 0 & \text{symbol 0} \end{cases}$$

Note that the modulated signal is still an on-off signal. Thus ASK is also known as on-off keying.

Frequency-Shift Keying (FSK)

In FSK, the modulated signal can be expressed as

$$x_c(t) = \begin{cases} A \cos \omega_1 t & \text{symbol 1} \\ A \cos \omega_2 t & \text{symbol 0} \end{cases}$$

Phase-Shift Keying (PSK)

In PSK, the modulated signal can be expressed as

$$x_c(t) = \begin{cases} A \cos \omega_o t & \text{symbol 1} \\ A \cos (\omega_o t + \pi) & \text{symbol 0} \end{cases}$$

Advantage of PSK

- Smaller Bandwidth.
- Signaling speed fastest up to 2400 baud.
- It is better for working under noisy condition.

Disadvantage of PSK

We need a synchronous detector and the associated circuit so that the receiver configuration of PSK system becomes more complex. To avoid this we use differential PSK, i.e., (DPSK) system which does not need synchronous detector.

Characteristic of DPSK

- The DPSK system avoids the use of synchronous detector. This is possible by generation of arbitrary waveform $b(t)$ at the modulator. The generation is simple.
- The error rate at DPSK is more, so that S/N ratio is less than PSK system. Bit error occur in pair or single.

Quadrature PSK (QPSK)

$[+45^\circ + 135^\circ - 135^\circ - 45^\circ]$.

We have seen that when a data stream whose bit duration is T_b is to be transmitted by PSK the channel bandwidth must be normally $2f_b$ where $f_b = (1/T_b)$.

QPSK allows bits to be transmitted using the half bandwidth required by PSK.

$$V(t) = b_e(t) A \cos \omega_o t + b_o(t) A \sin \omega_o t$$

$$\text{for PSK } BW = 2 \times (1/T_b)$$

$$\text{for QPSK } BW = 2 \times (1/2T_b)$$

$$PSK BW = (1/2) FSK BW$$

$$QPSK BW = (1/2) PSK BW$$

$$= (1/4) FSK BW$$

Probability of Error

The probability density of the noise $n_o(T)$ is *Gaussian with zero mean* as shown in figure.

Hence,

$$f[n_o(T)] = \frac{e^{-n_o^2(T)/2\sigma_o^2}}{\sqrt{2\pi\sigma_o^2}}$$

Probability Density of Noise sample

Hence,

$$P_e = \int_{VT/\tau}^{\infty} f[n_o(T) dn_o(T)] \\ = \frac{1}{2} \operatorname{erfc} \left(\frac{E_s}{\eta} \right)^{1/2}.$$

The Matched Filter

When the input noise is white, the optimum filter is known as a matched filter. In this case $G_n(f) = \eta/2$, and equation becomes.

$$H(f) = K \frac{P^*(f)}{\eta/2} e^{-j2\pi f\tau}$$

The impulse response of this filter is

$$h(t) = FT^{-1} [H(f)] \\ = \frac{2k}{\eta} \int_{-\infty}^{\infty} P^*(f) e^{-j2\pi fT} e^{j\pi ft} df \\ = \frac{2k}{\eta} \int_{-\infty}^{\infty} P^*(f) e^{-j2\pi fT} e^{j\pi f(t-T)} df \\ = \frac{2k}{\eta} \int_{-\infty}^{\infty} P(f) e^{-j2\pi fT} e^{j\pi f(t-T)} df \\ = \frac{2k}{\eta} \int_{-\infty}^{\infty} P^*(f) e^{-j2\pi fT} e^{j\pi f(t-T)} df$$

$$\left(\int_{-\infty}^{\infty} P^*(f) df = \int_{-\infty}^{\infty} P(f) df \right)$$

[Since $h^*(t) = h(t)$ for physical reliability of the filter].

$$= \frac{2k}{\eta} P(T-t) = \frac{2k}{\eta} [S_1(T-t) - S_2(T-t)]$$

$$[\therefore p(t) = S_1(t) - S_2(t)]$$

Probability of Error

The transmitted signal over a symbol interval $(0, T)$ is represented by

$$s_1(t) = \begin{cases} s_1(t) & 0 \leq t \leq T \text{ for } 1 \\ s_2(t) & 0 \leq t \leq T \text{ for } 0 \end{cases}$$

The comparator in the receiver is to compare the incoming signals with a threshold value and make a decision i.e.,

if $x > \lambda$, then H_1

if $z < \lambda$, then H_2

Where H_1 and H_2 are two hypothesis:

$\therefore$ The probability of error is:

$$P_e = P\left(\frac{H_2}{S_1}\right)P(S_1) + P\left(\frac{H_1}{S_2}\right)P(S_2)$$

Matched Filter

A matched filter is a linear designed to provided the maximum output SNR for a given transmitted signal.

Consider a known $s(t)$ plus additive white Gaussian noise AWGN $n(t)$ is the input to a LTI filter followed by a sampler.

Let $a(t)$ be the output of filter. Then at $t = T$, we have,

$$\left(\frac{S}{N}\right)_0 = \frac{a^2(T)}{E[N_0^2(T)]} = \frac{a^2(T)}{\sigma_{no}^2} \quad (1)$$

$$\text{Where } \sigma_{no}^2 = \frac{\eta}{2}$$

we need to find the filter frequency response $H_o(\omega)$ that maximum above equation. It can be shown that

$$\left(\frac{S}{N}\right)_0 \leq \frac{2}{\eta} \frac{1}{2\pi} \int_{-\infty}^{\infty} |S(\omega)|^2 d\omega = \frac{2E}{\eta} \quad (2)$$

$E \rightarrow$ Energy of input signal

$$\therefore \left(\frac{S}{N}\right)_{o_{\max}} = \frac{2E}{\eta}$$

The equality in equation (2) hold only if the optimum filter frequency response H_o is such that

$$H(\omega) = H_o(\omega) = S^*(\omega) e^{-j\omega T}$$

The impulse response $h(t)$ of this optimum filter is:

$$H(t) = F^{-1}[H(\omega)] = \begin{cases} s(T-t) & 0 \leq t \leq T \\ 0 & \text{otherwise} \end{cases}$$

Probability of Error with Gaussian Noise

The pdf of the Gaussian random noise n_o is:

$$f_{no}(\delta) = \frac{1}{\sqrt{2\pi} \sigma_{no}} e^{-\frac{\delta^2}{2\sigma_{no}^2}}$$

The probability of error can be found to be:

$$P_e = \operatorname{erfc} \left(\frac{a_1 - a_2}{2\sigma_{no}} \right) \quad (3)$$

Optimum Detection

To minimize P_e of equation (3), we need to find the linear filter that maximizes $\frac{(a_1 - a_2)}{(2\sigma_{no})}$ or that maximizes $\frac{(a_1 - a_2)^2}{\sigma_{no}^2}$

Where $a_1 - a_2$ is the difference of the signal components at the filter output, at time $t = t$ and σ_{no}^2 is the average output noise power.

If the filter is matched to the inputs $s_1(t) - s_2(t)$, then

$$\left(\frac{S}{N}\right)_0 = \frac{(a_1 - a_2)^2}{\sigma_{no}^2} = \frac{E_d}{\frac{\eta}{2}} = \frac{2E_d}{\eta}$$

Where $E_d = \int_0^T [s_1(t) - s_2(t)]^2 dt$ and

$\frac{\eta}{2}$ is PSD of noise at output.

$$P_e = \text{erfc}\left(\frac{a_1 - a_2}{2\sigma_{no}}\right) = \text{erfc}\left(\sqrt{\frac{E_d}{2\eta}}\right)$$

Error Probability performance of Binary Transmission Systems

$$P_e = \text{erfc}\left(\sqrt{\frac{A^2 T}{2\eta}}\right)$$

$$= \text{erfc}\left(\sqrt{\frac{E_b}{\eta}}\right)$$

Where $E_b = \frac{A^2 T}{2}$

Bipolar Baseband signaling:

$$P_e = \text{erfc}\left(\sqrt{\frac{2E_b}{\eta}}\right) \left(E_b = \frac{A^2 T}{2}\right)$$

$$ASK: P_e = \text{erfc}\left(\sqrt{\frac{E_b}{\eta}}\right) \left(E_b = \frac{A^2 T}{4}\right)$$

$$PSK: P_e = \text{erfc}\left(\sqrt{\frac{2E_b}{\eta}}\right) \left(E_b = \frac{A^2 T}{2}\right)$$

$$FSK: P_e = \text{erfc}\left(\sqrt{\frac{E_b}{\eta}}\right) \left(E_b = \frac{A^2 T}{2}\right)$$

10.8 BASICS OF TDMA, FDMA AND CDMA AND GSM

Time Division Multiplexing

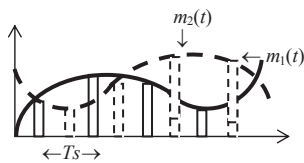


Fig. 10.38

$m_1(t)$ = Band limited signal f_{m1}
 $m_2(t)$ = Band limited signal f_{m2}

$T_s \uparrow (f_s \downarrow) \rightarrow$ Number of signals being Multiplexed. $\uparrow$

$$f_s \geq 2f_m$$

Velocity $V = \frac{1}{\sqrt{\mu\epsilon}}$ in any medium

Time of transmission of 1 sample = $[L/V]$

$$f_s \geq 2f_{m \max.} \text{ (sample/sec)}$$

where, L is distance between two points

V is Velocity of wave in that medium

Speed of commutator = f_s revolution/second

$\therefore$ 1 revolution time = $(1/f_s)$ second
 = T_s second.

TDM/PAM

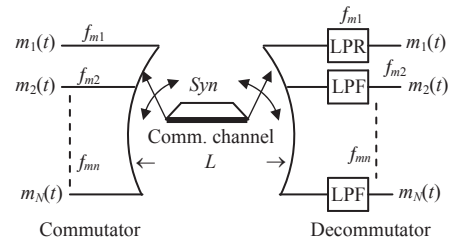
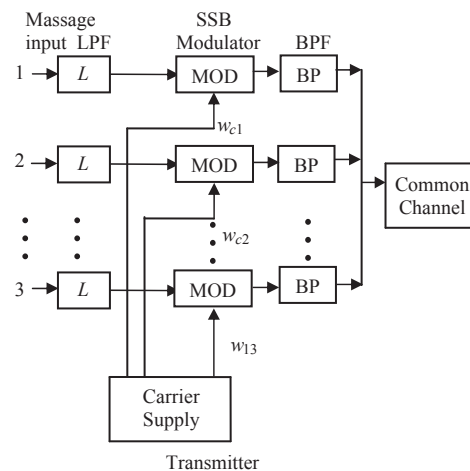
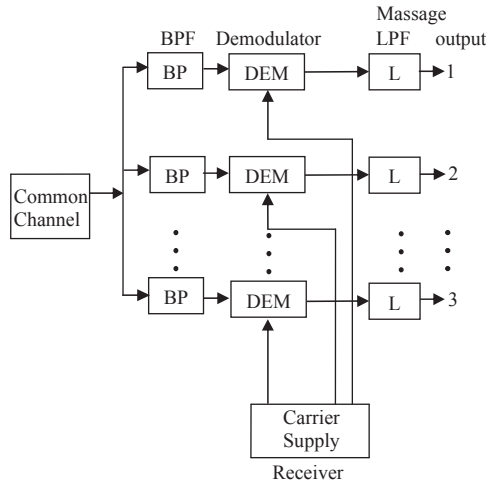


Fig. 10.39

Frequency-Division Multiplexing

Voice frequencies transmitted over telephone systems, for example, range from 300 to 3400 Hz. To transmit a number of these signals over the same channel, the signals must be kept apart so that they do not interfere with each other, and thus they can be separated at the receiving end. This is accomplished by separating the signals either in frequency or in time. The technique of separating the signals is referred to as frequency-division multiplexing (FDM).





Block diagram of FDM system

Fig. 10.40

Comparison between FDM and TDM

There are two methods of multiplexing, viz. FDM (frequency Division Multiplexing) and TDM (Time Division Multiplexing). The basic difference between them is that in FDM the frequency scale is shared by different signals; in TDM the time scale is shared by different signals, as shown in figure. The bandwidth requirement of AM/SSB and PAM is n_{fm} Hz, and that of AM/DSB and PAM/AM is $2n_{fm}$ Hz. Thus it can be said that the bandwidth requirement of the FDM and TDM system is the same. TDM is superior to FDM in the following ways:

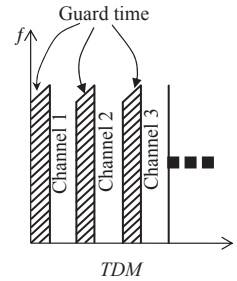
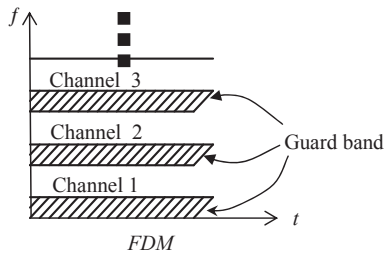


Fig. 10.41

1. In the FDM system, different carriers are to be generated for different channels. Also, as each channel occupies a different frequency band, different band pass filters are required. On the other hand, in TDM system, all the channels require identical circuits, consisting of simple synchronous switches, gates, and a low pass filter. Thus the circuitry needed in the TDM system is much simpler than the one needed in the FDM system.
2. The non-linearities in the various amplifiers of an FDM system produce harmonic distortion and, hence, they introduce interference within the channels. Therefore, the non-linearity requirements of an FDM system are much more stringent than those for a single channel. On the other hand, in a TDM system, the signals from different channels are allotted different time slots and they are not applied to the system simultaneously. Hence, the non-linearity requirements of a TDM system are the same as those for a single channel. Thus the TDM system is relatively immune to interference within the channels (inter channel cross-talk) as compared to the FDM system.

Pre-emphasis filter can be represented as:

$$H_{PE}(f) = K \left(1 + j \frac{f}{f_1} \right)$$

Similarly De-emphasis filter can be represented as

$$H_{DE}(f) = \frac{1}{K} \left(1 + j \frac{f}{f_1} \right)^{-1}$$

Note:

PE-DE circuit is of no use in DSB-SC modulation.

QUESTION BANK

LEVEL 1

1. In the spectrum of a FM wave
 - (a) The carrier frequency cannot disappear
 - (b) The carrier frequency disappears when on the modulation index is large
 - (c) The amplitude of any sideband depends on the modulation index
 - (d) The total number of side bands depends on the modulation index
2. In FM reception, amplitude disturbances due to static change
 - (a) Reduce the signal frequencies
 - (b) Increase the signal frequencies
 - (c) Disturb the signal frequencies
 - (d) Do not affect the signal frequencies
3. Under identical conditions FM and PM are indistinguishable for a single modulating frequency. Now if the modulating frequency is increased
 - (a) PM modulation index will remain constant, whereas FM modulation index will increase
 - (b) PM modulation index will remain constant. Whereas FM modulation index will decrease
 - (c) PM modulation index will decrease and FM modulation index will increase
 - (d) Both PM as well as FM modulation indices will increase
4. Which of the following pulse communication system is inherently immune to noise?
 - (a) PPM
 - (b) PCM
 - (c) PWM
 - (d) PAM
5. Companding is used
 - (a) To overcome quantising noise in PCM
 - (b) In PWM receivers to reduce impulse noise
 - (c) To protect small signals in PCM from quantising noise
 - (d) None of the above
6. The most commonly used system of modulation for **telegraphy** is
 - (a) single tone modulation
 - (b) On-off keying
 - (c) Frequency shift keying
 - (d) Pulse code modulation
7. Which of the following statements about receivers is false?
 - (a) Double conversion is used to improve image rejection
 - (b) Double conversion is used to improve selectivity
 - (c) Variable sensitivity is used to improve selectivity
 - (d) Variable sensitivity is used to eliminate selective fading
8. The IF stage of a receiver employs
 - (a) Capacitive coupling
 - (b) Impedance coupling
 - (c) Double-tuned transformer coupling
 - (d) Single-tuned transformer coupling
9. Quantizing noise is produced in
 - (a) FDM
 - (b) PCM
 - (c) All modulation systems
 - (d) All pulse modulation systems
10. Electromagnetic waves may be diffracted
 - (a) By reflection from the ground
 - (b) When encountered with a spherical wave front
 - (c) Around the edge of a sharp obstacle
 - (d) While passing through a large slot
11. The absorption of radiowaves by the atmosphere depends on
 - (a) Polarization of the waves
 - (b) Polarization of the atmosphere
 - (c) Distance from the transmitter
 - (d) Frequency.
12. As far high frequency propagation is concerned, which of the following layer is of least importance?
 - (a) D-layer
 - (b) E-layer
 - (c) F₁ layer
 - (d) F₂ layer
13. An isotropic source of radiation is one that
 - (a) Absorbs all radiations
 - (b) Does not absorb radiations
 - (c) Changes the direction of radiations
 - (d) Radiates uniformly in all direction in space
14. The ionizing agents for ionosphere are
 - (a) Ultraviolet rays
 - (b) Alpha, beta and gamma radiations
 - (c) Cosmic rays
 - (d) All of the above
15. The radiation pattern of a parabolic antenna is
 - (a) Omni-directional
 - (b) A figure of eight
 - (c) Highly directional
 - (d) Multi-directional
16. High frequency waves follow
 - (a) The line of sight direction
 - (b) The ground wave propagation
 - (c) The ionosphere propagation
 - (d) The curvilinear propagation
17. Skip distance is independent of
 - (a) Frequency
 - (b) State of ionisation
 - (c) Transmitting power
 - (d) Type of wave propagation.
18. The most common detector used in an AM radio broadcast receiver is
 - (a) envelope detector
 - (b) coherent detector
 - (c) discriminator
 - (d) ratio detector

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19. In radar sets, the resolution depends upon pulse
 - (a) Average power
 - (b) Rise time
 - (c) Width
 - (d) Repetition frequency
20. Which one of the following system offers the best trade off between bandwidth and S/N ratio
 - (a) PAM
 - (b) PDM
 - (c) PPM
 - (d) PCM
21. Which one of following system gives the highest figure of merit (a measure of the noise performance)?
 - (a) WBFM
 - (b) NBFM
 - (c) AM
 - (d) SSB
22. If on doubling the modulating frequency the modulation index is halved, and the modulating voltage remains constant, then the system is
 - (a) Amplitude modulated
 - (b) Frequency modulated
 - (c) Phase modulated
 - (d) Pulse modulated
23. In television system, VSB, modulation is preferred to SSB in order to
 - (a) Save on bandwidth
 - (b) Enable demodulation using an envelope detector
 - (c) Simplify generation
 - (d) Save on signal power
24. The two fundamental physical limitations faced by an engineer in designing a communication system would include
 - (a) Bandwidth and interference
 - (b) Interference and distortion
 - (c) Distortion and noise
 - (d) Noise and bandwidth
25. The fidelity of a receiver relates to variation of the output with the modulating frequency when the output load is
 - (a) Resistive
 - (b) Inductive
 - (c) Capacitive
 - (d) A combination of the above three
26. In T.V transmission picture signal is amplitude modulated and sound signal is frequency modulated. This is done because
 - (a) It is not possible to frequency modulate the picture signal
 - (b) Bandwidth requirement is minimized
 - (c) Sound signal is more susceptible to noise than picture signal
 - (d) Synchronization of picture frames becomes easier
27. Entropy is basically a measure of
 - (a) Rate of information
 - (b) Average information
 - (c) Probability of information
 - (d) Channel capacity for transmission of information
28. Frequency shifting keying (FSK) system is used presently in communication of data through satellite. The technique uses
 - (a) Some frequency signal for transmission of ONE, and no signal for transmission for ZERO
 - (b) Constant frequency signal for ONE and no signal for ONE
 - (c) One set frequencies for ONE, and another set of frequency of ZERO
 - (d) Pulses are transmitted through satellite and frequency etc., has no relevance
29. A practical **local oscillator** in the super heterodyne type of communication receiver is
 - (a) An R-C phase shift oscillator
 - (b) A Colpitts oscillator
 - (c) A Hartley oscillator
 - (d) A phase-Shift type of harmonic oscillator that employs L-C resonator
30. Keyed AGC is AGC that
 - (a) Works only with Morse code
 - (b) Is achieved when keyed by the transmitting signal
 - (c) Is used in TV receivers so that transmitted pictures does not effect the AGC
 - (d) Is used in colour TV receivers so that transmitted colour has no effect on the AGC
31. Which one of the following is the advantage of **base modulation over collector modulation** of a transistor Class C amplifier?
 - (a) Requires lower modulation power
 - (b) Higher power output per transistor
 - (c) Better efficiency
 - (d) Better linearity
32. Equalizing pulses in TV are placed during the
 - (a) Vertical blanking period
 - (b) Horizontal blanking period
 - (c) Serration
 - (d) Horizontal retrace
33. The most useful approach to radar system for monitoring the speed of moving vehicles is
 - (a) Pulsed radar
 - (b) Monopulse
 - (c) Doppler radar
 - (d) Auto-tracking radar
34. To couple a coaxial line to a parallel wire line it is best to use a
 - (a) Slotted line
 - (b) Balun
 - (c) Directional coupler
 - (d) Quarter wave transformer
35. Avalanche photodiodes are preferred over PIN diodes in optical communication systems because of
 - (a) Speed of operation
 - (b) Higher sensitivity
 - (c) Larger bandwidth
 - (d) Larger power handling capacity
36. The capacity of a channel is given by the
 - (a) Number of digits used in coding
 - (b) Volume of information it can take
 - (c) Maximum rate of information transmitted
 - (d) Bandwidth required for information
37. The most useful modulation technique for high fidelity audio broadcasting on radio in current practices is
 - (a) Amplitude modulation
 - (b) Frequency modulation

- (c) Pulse amplitude modulation
(d) Pulse code modulation
38. In conventional AM superheterodyne receivers, the detectors employed to extract intelligence include
(a) Peak detectors (b) Ratio detectors
(c) Phase locked loops (d) Slop detectors
39. In TV systems, the modulation methods employed for video and audio signals are
(a) Both amplitude modulation
(b) Both frequency modulation
(c) Respectively amplitude modulation and frequency modulation
(d) Respectively frequency modulation and amplitude modulation
40. The signal to quantization noise ratio in an n -bit PCM system
(a) Depends upon the sampling frequency employed
(b) Is independent of the value of n
(c) Decreases with increases value of n
(d) Increase with increases value of n
41. A PWM signal can be generated by
(a) An astable multivibrator
(b) A monostable multivibrator
(c) Integrating a PPM signal
(d) Differentiating a PPM signal
42. What changes would be necessary in block C if FM signals are to be received (Figure 1)?
(a) This block becomes redundant
(b) A FM detector would be required
(c) A high frequency signal generator
(d) An additional local oscillator will be needed
43. The function of **padders** in ratio receivers is to
(a) Improve sensitivity
(b) Reduce image frequency rejection
(c) Reduce noise
(d) Improve tracking
44. Which of the following requires a synchronizing signal?
(a) Single channel PPM system
(b) PAM
(c) PDM
(d) all of the above
45. The **power spectral density** of white noise
(a) Varies as square root of frequency
(b) Varies as inverse of frequency
(c) Varies as square of frequency
(d) Is constant with frequency
46. Which of the following is a **unit of loudness**?
(a) mel (b) decibel
(c) sone (d) phon
47. A **carbon microphone** is a variable
(a) resistance (b) inductance
(c) capacitance (d) all of the above
48. **Shannon's law** relates
(a) Antenna gain to bandwidth
(b) Frequency to antenna gain
(c) Antenna gain to transmission losses
(d) Information carrying capacity to S/N ratio
49. **Frequency shift keying** is used mostly in
(a) radio transmission (b) telegraphy
(c) telephony (d) none of these
50. In **PCM** if the **transmission path** is very long
(a) Repeater stations are used
(b) Pulse width may be increased
(c) Pulse amplitude is increased
(d) Pulse spacing is reduced
51. A signal having uniformly distributed amplitude in the interval $(-V, +V)$ is to be encoded using **PCM with uniform equalization**. The signal to quantizing noise ratio is determined by the
(a) Dynamic range of the signal
(b) Sampling rate
(c) Number of quantizing levels
(d) Power spectrum of signal
52. In **PCM**, the **biggest disadvantage** as compared to AM is
(a) larger bandwidth
(b) larger noise
(c) Inability to handle analog signals
(d) Horizontal retrace
53. **MODEM** stands for
(a) Modulator at transmitting side and detector at the receiving side
(b) Which deals with analog signal and shown digital side
(c) Analog to digital at transmitting side and digital to analog at a receiving side
(d) A device which deals with digital signals only
54. The **envelope detector** is a/an
(a) Synchronous detector (b) Asynchronous detector
(c) Product demodulator (d) Coherent detector
55. The output of a **piezoelectric crystal** has
(a) Low amplitude and low impedance
(b) High amplitude and high impedance
(c) Low amplitude and high impedance
(d) High amplitude and low impedance
56. A comparison of **frequency division** and **time division multiplexing** systems shows that
(a) FDM requires lower bandwidth, but TDM has greater noise immunity
(b) FDM has greater noise immunity and requires lower bandwidth than TDM
(c) FDM requires channel synchronization, while TDM has greater noise immunity
(d) FDM requires more while TDM requires band pass filter
57. A **correlation receiver** consists of
(a) A multiplier and an integrator
(b) An integrator only

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- (c) A multiplier only
(d) An adder and integrator
58. To **balance out-the local oscillator noise** at the input to the intermediate frequency or to IF amplifier in superhetrodyne receivers, the microwave circuit used is
(a) Balanced amplifier (b) Balanced isolator
(c) Balanced phase shifter (d) Balanced microwave mixer
59. The **signal-to-quantization** noise ratio in a **PCM** system depends upon
(a) Sampling rate
(b) Number of Quantization levels
(c) Message-signal bandwidth
(d) Size of the transmission system
60. The **rate at which information** can be passed through a telecommunication channel depends on the
(a) A carrier frequency (b) Bandwidth
(c) Transmission loss (d) Transmitter power
61. **PCM system** require regenerative repeaters over long distance. The correct sequence of the operations which such a repeater performs is
(a) Timing, equalization and decision making
(b) Equalization, timing and decision making
(c) Timing, thresholding (decision) and equalization
(d) Thresholding, timing and equalization
62. In **push button keypad dialing** in telephony, touching a button generates a tone which is a
(a) combination of two frequencies
(b) single frequency
(c) chirp tone
(d) sequence of pulses
63. In a **low level modulation AM system**, the amplifiers following the modulated stage can be
(a) linear amplifiers (b) harmonic generators
(c) class C power amp (d) class B untuned amp
64. In the **generation of modulated** signal, a **varactors diode** can be used for
(a) FM generation only (b) AM generation only
(c) PM generation only (d) Both AM and PM generation
65. **Pre-emphasis in FM systems** involves
(a) Compression of the modulating signal
(b) Expansion of the modulating signal
(c) Amplification of lower frequency components of the modulating signal
(d) Amplification of higher frequency components of the modulating signal
66. The choice of the product **RC is an envelope detector** using a diode and RC circuit is governed by
(a) Both the lowest and the highest modulation frequencies
(b) Only the depth of modulation
(c) The depth of modulation and the lowest modulation frequency
(d) The depth of modulation and the highest modulation frequency
67. As the **modulation index of a FM** signal with sinusoidal modulation is increased from zero to three, the power in the sideband component will
(a) Increase continuously
(b) Decrease continuously
(c) First increase, attain a maximum and then decrease
(d) First decreases become zero and then increase
68. **Double spotting** in super heterodyne receivers is caused by
(a) Poor front-end rejection
(b) Misalignment of receiver
(c) Detuning of one or more IF stages
(d) Non-functioning of AGC
69. The amplifiers which are inserted at intervals to amplify the signal and compensate for **transmission** loss on the cable are called
(a) line amp (b) equalizing amp
(c) companders (d) repeaters
70. In an **ADM transmission** system, the output signal amplitudes for 1's and 0's are
(a) Fixed and the repetition rate is also fixed
(b) Fixed but the repetition rate is variable
(c) Variable and the repetition rate is also variable
(d) Variable but the repetition rate is fixed
71. If, in a particular **digital communication application**, the receiver designed is an optimum **coherent receiver**, the channel noise is white and bits are transmitted using rectangular pulses, then which one of the following statements would be **INCONSISTENT**?
The Receiver is
(a) A correlator
(b) Matched filter receiver
(c) An integrate and dump receiver
(d) Sample, hold and dump receiver
72. The use of **non-uniform quantization** leads to
(a) Reduction in transmission bandwidth
(b) Increase in maximum SNR
(c) Increase in SNR for low level signals
(d) Simplification of quantization process
73. The **baud rate** is
(a) Always equal to the bit transfer rate
(b) Equal to twice the bandwidth of an ideal channel
(c) Not equal to the signalling rate
(d) Equal to one-half the bandwidth of ideal channel
74. **Preset equalization** following the same process as adaptive equalization except that the equalization is set prior to transmission and then un-dated during breaks in transmission using
(a) Special test sequences (b) block codes
(c) BCD (d) correlators
75. **Time division multiplexing** requires
(a) Constant data transmission
(b) Transmission of data samples
(c) Transmission of data at random
(d) Transmission of data of only one measured

LEVEL 2

1. The **spectral density of white noise** is constant
 - (a) exponential
 - (b) uniform
 - (c) Poisson
 - (d) Gaussian
 2. In **phase modulation**, the frequency deviation is
 - (a) Independent of the modulating signal frequency
 - (b) Increasingly proportional to the modulating signal frequency
 - (c) Directly proportional to the modulating signal frequency
 - (d) Inversely proportional to the square root of the modulating frequency
 3. For **distortion less transmission** through a channel, the channel should be such that
 - (a) Its attenuation response is an even function and phase response is an odd function of frequency.
 - (b) Its attenuation response is flat and phase response is linear with frequency
 - (c) The ratio of line inductance to line capacitance is constant
 - (d) Its termination is by a matched impedance
 4. Quadrature multiplexing is
 - (a) Same as FDM
 - (b) Same as TDM
 - (c) A combination of FDM and TDM
 - (d) The scheme where same carrier frequency is used for two different signals
 5. Which one of the following statements regarding the **threshold effect in demodulator** is correct?
 - (a) It is exhibited by all demodulators when the input signal to noise ratio is low
 - (b) It is the rapid fall in output signal to noise ratio when the input signal to noise ratio falls below a particular value
 - (c) It is the property exhibited by all AM suppressed carrier coherent demodulators
 - (d) It is the property exhibited by correlation receivers
 6. Leak type bias is used in a plate modulated class C amplifier
 - (a) Increase the bandwidth
 - (b) Prevent excessive grid current
 - (c) Prevent tuned circuit damping
 - (d) Prevent over modulation
 7. Which one of the following circuits transmits two messages simultaneously in one direction?
 - (a) Duplex
 - (b) Diplex
 - (c) Simplex
 - (d) Quadruplex
 8. The performance of the **DPCM-Coder** improves as the
 - (a) Input probability density becomes more and more Gaussian
 - (b) Input power spectral density tends to be white
 - (c) Input dynamic range increases
 - (d) Sample-to-sample correlation of the input increases
 9. A **satellite channel** can be fairly accurately modeled as
 - (a) Random delay channel
 - (b) Panic button channel
 10. Consider the following statements
If the maximum range of a radar has to be doubled
 1. The peak transmitted power may be increased 16 fold
 2. The antenna diameter may be doubled
 3. The sensitivity of the receiver may be doubled
 4. The transmitted pulse width may be doubled
 Which of these statements are correct?
 - (a) 1 and 2
 - (b) 2 and 3
 - (c) 3 and 4
 - (d) 1 and 4
 11. If large amount of information is to be transmitted in a small amount of time, we require
 - (a) Low-frequency signals
 - (b) Narrow-band signals
 - (c) Wide-band signals
 - (d) High-frequency signals
 12. A modulator is a device to
 - (a) Separate two frequencies
 - (b) Impress the information on to a radio frequency carrier
 - (c) Extract information from the carrier
 - (d) Amplify the audio frequency signal
 13. A modulation technique in which bandwidth of the modulated signal is extended well beyond the bandwidth of the modulating signal, independent of the modulating signal bandwidth, is called
 - (a) Wide-band modulation
 - (b) Extended bandwidth modulation
 - (c) Spread spectrum modulation
 - (d) Narrow band modulation
 14. Which of the following desirable features are possessed by SSB in comparison to AM
 1. Less power is required
 2. Bandwidth required is less
 3. Antenna size can be reduced
 4. Lower frequency can be used
 Select the correct answer using the codes given below
Codes
 - (a) 3 and 4
 - (b) 2, 3 and 4
 - (c) 1 and 2
 - (d) 1, 2 and 4
 15. Power spectral density of a signal is
 - (a) Complex even and non negative
 - (b) Real, even and non negative
 - (c) Real, even and negative
 - (d) Complex odd and non negative
 16. Which one of the following multiplexing techniques involves signals composed of light beams?
 - (a) CDM
 - (b) FDM
 - (c) TDM
 - (d) WDM
 17. In a communication system, a process for which statistical averages and time averages are equal, is called
 - (a) Stationary
 - (b) Ergodic
 - (c) Gaussian
 - (d) BIBO stable

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18. In which type of the switching gives below, entire capacity of a dedicated link is used?
 - (a) Circuit switching
 - (b) Data gram packet switching
 - (c) Virtual circuit packet switching
 - (d) Message switching
19. In TDM non-essential frequency components of the modulating signal are removed by
 - (a) Sampler
 - (b) Attenuator
 - (c) Pre-alias filter
 - (d) Modulator
20. Which one of the following statements is correct? For coherent detection of digital
 - (a) Synchronized in time only
 - (b) Synchronized in phase only
 - (c) Synchronized in time and phase
 - (d) Unsynchronized
21. Which one of the following statements is correct? Quantizing noise is produced in
 - (a) All pulse modulation systems
 - (b) PCM
 - (c) All modulation systems
 - (d) FDM
22. Which one of the following statement is correct? Noise has the greatest effect in a communication system when it interferes with the signal
 - (a) In the transmitter
 - (b) In the channel
 - (c) In the receiver
 - (d) In the transducer
23. The **channel capacity** of a noiseless channel is equal to
 - (a) Rate at which information is transmitted
 - (b) Signaling speed
 - (c) Bandwidth
 - (d) Bandwidth-SNR product
24. To overcome slope over load problem, which type of the integrator is used in delta modulation?
 - (a) Fixed slope integrator
 - (b) Variable slope integrator
 - (c) Linear slope integrator
 - (d) Bipolar integrator
25. **Quantization** noise occurs in
 - (a) Pulse amplifier modulation
 - (b) Pulse width modulation
 - (c) Pulse code modulation
 - (d) Pulse position modulation
26. Single loop ionospheric transmission systems can have a range up-to
 - (a) 50 km
 - (b) 200 km
 - (c) 500 km
 - (d) 1000 km
27. In a line-of sight system, the receiving and transmitting antenna heights are respectively 10 m and 100 m above the surface of the earth. The range of the system will be approximately
 - (a) 20 km
 - (b) 30 km
 - (c) 40 km
 - (d) 50 km
28. A $\lambda/2$ dipole antenna radiates 20 watts at 200 MHz having a gain of 1.64. A receiving $\lambda/2$ dipole antenna is 50 km away from the transmitting antenna. The antennas are positioned for optimum transmission and reception and the effective length of the receiving antenna is λ/π . λ being the wavelength of the transmitted wave. The open circuit voltage in the receiving antenna will be
 - (a) $400 \mu\text{V}$
 - (b) $300 \mu\text{V}$
 - (c) $200 \mu\text{V}$
 - (d) $100 \mu\text{V}$
29. A signal $\cos^2 200 \pi t$ is multiplied by the signal $\sin 200 \pi t$. The frequency which will be generated in this process include
 - (a) DC, 50 Hz, 100 Hz, 300 Hz
 - (b) DC, 50 Hz, 200 Hz
 - (c) 100 Hz, 150 Hz, 250 Hz
 - (d) 100 Hz, 200 Hz, 300 Hz
30. In a narrow band FM system, the highest modulating frequency is f_m . The bandwidth of the system will be
 - (a) $6 f_m$
 - (b) f_m
 - (c) $2 f_m$
 - (d) $10 f_m$
31. A telephone channel with PCM gives good performance at a transmission rate of 64 k bits/s with companding and complex version of delta modulation (DM) to achieve the same performance, the transmission rate must be close to
 - (a) 64 k bits/s
 - (b) 100 k bits/s
 - (c) 64 M bits/s
 - (d) 100 M bits/s
32. The rms **thermal noise** currents of the resistance are I_1 , I_2 and I_3 respectively. If these resistors are connected in parallel, the total equivalent noise current 'I' will be
 - (a) $I_1 + I_2 + I_3$
 - (b) $(I_1 I_2 I_3)^{1/3}$
 - (c) $\sqrt{I_1^2 + I_2^2 + I_3^2}$
 - (d) $\sqrt{I_1} + \sqrt{I_2} + \sqrt{I_3}$
33. A carrier is simultaneously modulated by two sine waves with modulation indices of 0.4 and 0.3. The resultant modulation index will be
 - (a) 1.0
 - (b) 0.7
 - (c) 0.5
 - (d) 0.35
34. In a 100% amplitude modulated signal if the total transmitted power is P, then the carrier power will be
 - (a) $\frac{2}{3} P$
 - (b) $\frac{1}{2} P$
 - (c) $\frac{1}{3} P$
 - (d) $\frac{1}{4} P$
35. A speech signal occupying the bandwidth of 300 Hz to 3 kHz is converted into PCM format for use in digital communication. If the sampling frequency is 8 kHz and each sample is quantized into 256 levels, then the output bit rate will be
 - (a) 3 kb/s
 - (b) 8 kb/s
 - (c) 64 kb/s
 - (d) 256 kb/s
36. A broadcast radio receiver with IF = 455 kHz is tuned to 1500 kHz. The image frequency will be
 - (a) 1045 kHz
 - (b) 1500 kHz
 - (c) 1955 kHz
 - (d) 2410 kHz

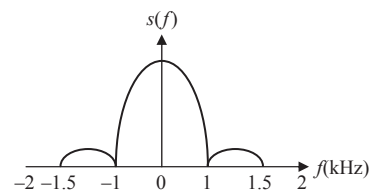
37. For an AM having a power of 800 W at its carrier frequency and modulation index of 90%, the power content of each side-band is
 (a) 81 W (b) 162 W
 (c) 200 W (d) 400 W
38. Noise voltage varies in a resistor as
 (a) 4 KTRB (b) $\sqrt{4 \text{ KTRB}}$
 (c) $\sqrt{2E \text{ IpB}}$ (d) $\sqrt{2e \text{ Ip B} \cdot R}$
39. One decibel represents a power ratio of
 (a) 1.26 : 1 (b) 2 : 1
 (c) 10 : 1 (d) 20 : 1
40. If IF signal frequency is 470 kHz, what will be the frequency of block D when frequency of incoming signal is 1.15 MHz.
 (a) 1.15 MHz (b) 1.620 MHz
 (c) 2.090 MHz (d) $\sqrt{(2.09)} \text{ MHz}$
41. The maximum permitted data rate for this system is
 (a) 200 bits/second (b) 200 baud
 (c) 100 baud (d) 1080 bits/second
42. In case a zero-crossing detector used in this system indicates a time of 510 microseconds, the state received would be
 (a) 1 (b) 0
 (c) [1/0] (d) [0/1]
43. A 60 kHz carrier is amplitude modulated by the speech band of 300 to 3000 Hz. The range of upper side bands will be
 (a) 60.3 to 63 kHz (b) 60 to 59.7 kHz
 (c) 57 to 59.7 kHz (d) 56.7 to 56.3 kHz
44. For a signal amplitude modulated to a depth of 100% by a sinusoidal signal, the power is....as the power of un modulated carrier
 (a) same (b) $\sqrt{2}$ times
 (c) 1.5 times (d) twice
45. An FM radio receiver is tuned to a 90.6 MHz broadcast station. It will receive an image frequency of
 (a) 110 MHz (b) 112 MHz
 (c) 114 MHz (d) 120 MHz
46. A certain communication system uses RF pulses with four possible amplitude levels. If an information rate of 10^6 bit/sec is desired, the minimum practical value of the carrier frequency should be:
 (a) 1 MHz (b) 2.5 MHz
 (c) 0.5 MHz (d) 10 MHz
47. The minimum value of m_f for an FM system required to produce a noticeable improvement in S/N ratio over a comparable AM system with $m_a = 1$ is
 (a) $\sqrt{3}$ (b) $\sqrt{2}$
 (c) $1\left(\frac{1}{\sqrt{2}}\right)$ (d) $\frac{1}{\sqrt{2}}$
48. A 1000 kHz carrier is simultaneously modulated with 300 Hz and 2 kHz audio sine waves. Which of the following frequencies will not be present in the output?
 (a) 998 kHz (b) 999.7 kHz
 (c) 1000.3 kHz (d) 700 kHz
49. A carrier is simultaneously modulated by two sine waves with modulation indices of 0.3 and 0.4. If the modulated power is 10 kW, what is the total modulated power?
 (a) 11.25 kW (b) 10 kW
 (c) 10.125 kW (d) 10.5 kW
50. The saving is power in a DSBSC system modulated at 80% is
 (a) Nil (b) 80%
 (c) 75.76% (d) 50%
51. An image uses 512×512 picture elements. Each of the picture elements can take any of the 8 distinguishable intensity levels. The maximum entropy in the above image will be
 (a) 2097152 bits (b) 786432 bits
 (c) 648 bits (d) 144 bits
52. In a PCM the amplitude levels are transmitted in a 7 unit code. The sampling is done at the rate of 10 Hz. The bandwidth should be
 (a) 5 kHz (b) 35 kHz
 (c) 70 kHz (d) 5 MHz
53. A RF carrier of 12 kV at 1 MHz is amplitude modulated by a 1 KHz signal of 6 kV peak. The modulation pattern is observed on a CRO calibrated suitably. The voltage indicated will be
 (a) 18 kV (b) 1.001 kV
 (c) 18 V (d) 36 kV
54. The d.c voltage on a plate modulated class C amplifier is 8 kV and the peak modulating voltage is 4 kV. The peak RF voltage delivered to the load is
 (a) 32 kV (b) 12 kV
 (c) 0.5 kV (d) 24 kV
55. Pulse code modulation (PCM) employing 4-bit code is used to transmit a data signal having frequency components from dc to 2 KHz. The minimum bandwidth of the carrier channel should be
 (a) 2 kHz (b) 4 kHz
 (c) 8 kHz (d) 16 kHz
56. A communication channel disturbed by additive white Gaussian noise has a bandwidth of 4 kHz and SNR of 15. The highest transmission rate that such a channel can support (in k-bits/sec) is
 (a) 16 (b) 1.6
 (c) 3.2 (d) 60
57. A discrete zero memory information source has 40 symbols and each symbol is equally likely. The minimum number of bits required to code the source with uniform length code and the entropy of the source are respectively
 (a) 5, 5.03 (b) 6, 5.83
 (c) 5, 6.64 (d) 6, 5.32
58. If each stage had a gain of 10 dB, and noise figure of 10 dB, then the overall noise figure of a two-stage cascade amplifier will be
 (a) 10 (b) 1.09
 (c) 1.0 (d) 10.9

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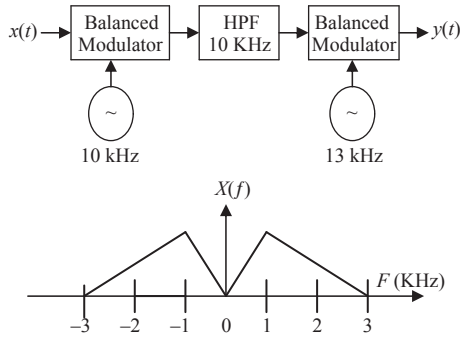
59. In a **PCM** system the number of quantization levels are 16 and the maximum signal frequency is 4 KHz, the bit transmission rate is
 (a) 64 K bits/sec (b) 16 K bits/sec
 (c) 32 K bits/sec (d) 32 bits/sec
60. An amplifier operating over the frequency range of 18 to 20 MHz has a 10 K Ω input resistance. The **RMS noise voltage** at the input to the amplifier at ambient temperature of 27°C is (Assume the Boltzman constant value as 1.38×10^{-23} J/K)
 (a) 18.2 micro-volts (b) 17.2 micro-volts
 (c) 16.2 micro-volts (d) 14.2 micro-volts
61. If **carrier modulated by a digital bit** stream had one of the possible phases of 0, 90, 180 and 270 degrees, then the modulation is called
 (a) BPSK (b) QPSK
 (c) QAM (d) MSK
62. An **FM signal** with a deviation δ is passed through a mixer and has its frequency reduced fivefold. The deviation in the output of the mixer is
 (a) 5δ (b) intermediate
 (c) $\delta/5$ (d) δ
63. A **TDM link** has 20 signal channels and each channel is sampled 8000 times/sec. Each sample is represented by seven binary bits and contains an additional bit for synchronization. The total bit rate for the TDM link is
 (a) 1180 K bits/sec (b) 1280 K bits/sec
 (c) 1180 M bits/sec (d) 1280 M bits/sec
64. The **attenuation in a telephone cable** is 1 dB per km and the transmitted voltage is 1 V. The voltage received 1000 km away is
 (a) 10^{-100} V (b) 10^{-50} V
 (c) 10^{-3} V (d) 10^{-4} V
65. A message signal band limited to 5 KHz is **sampled** at the minimum rate as dictated by the sampling theorem. The number of **quantization levels** is 64. If the samples are encoded in binary form, the transmission rate is
 (a) 60 kbps (b) 50 kbps
 (c) 32 kbps (d) 10 kbps
66. The **channel capacity** under the Gaussian noise environment for a discrete memory-less channel with a bandwidth of 4 MHz and SNR of 31 is
 (a) 20 Mbps (b) 4 Mbps
 (c) 8 kbps (d) 4 kbps
67. In **FM sound broadcasting** system, the maximum frequency deviation is usually
 (a) 15 kHz (b) 75 kHz
 (c) 200 kHz (d) 5.2 MHz
68. The **entropy of a message source** generating four messages with probabilities 0.5, 0.25, 0.125 and 0.125 is
 (a) 1.0 bit/message (b) 1.75 bits/message
 (c) 3.32 bit/message (d) 5.93 bits/message
69. The **capacity of an analog communication channel** with 4 KHz bandwidth and 15db SNR is approxi-mately
 (a) 20,000 bps (b) 16,00 bps
 (c) 10,000 bps (d) 8,000 bps
70. A communication system is used to transmit one of **16 possible signals**. Assume that transmission is accomplish by encoding the signals into binary digits. Further assume that signal are equally likely to occur. If each binary digit requires 1m sec. For transmission, then how much information (in bits) is transmitted by the system in 8 microseconds?
 (a) 8 (b) 16
 (c) 4 (d) 2
71. The **noise figure of a receiver** is 1.6. Its **equivalent noise temperature** is
 (a) 464.00 K (b) 174.00 K
 (c) 108.75 K (d) 181.25 K
72. In a 100 line exchange with 10 first selectors, the number of **line finders** required
 (a) is 10
 (b) is 100
 (c) would depend upon the traffic flow
 (d) is busy-hour calling rate
73. In a **carrier telephone system**, a **group occupies a frequency band** of
 (a) 36 to 48 KHz (b) 60 to 108 KHz
 (c) 92 to 140 KHz (d) 140 to 172 KHz
74. Two carriers 40 MHz and 80 MHz respectively are frequency modulated by a signal of frequency 4 KHz, such that the bandwidth of the FM signal in the two cases are same. The **peak deviation** in the two cases are in the ratio of
 (a) 1 : 4 (b) 1 : 2
 (c) 1 : 1 (d) 2 : 1
75. In an **amplitude modulated system**, if the total power is 600 W and power in carrier is 400 W, then the modulation index is
 (a) 0.5 (b) 0.75
 (c) 0.9 (d) 1

LEVEL 3

1. A deterministic signal has the power spectrum given in figure. The minimum sampling rate needed to completely represent this signal is



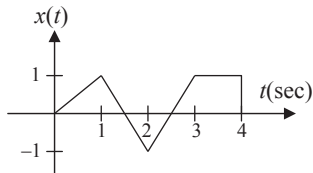
- (a) 1 kHz (b) 2 kHz
 (c) 3 kHz (d) none of the above
2. Consider as system shown in figure. Let $X(f)$ and $Y(f)$ denote the Fourier transforms of $x(t)$ and $y(t)$ respectively. The ideal HPF has the cutoff frequency 10 kHz



The positive frequency $Y(f)$ has spectral peaks are

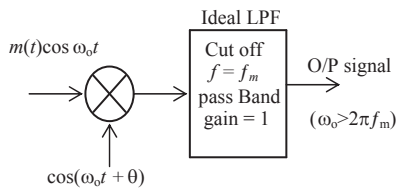
- (a) 1 kHz and 24 kHz (b) 2 kHz and 24 kHz
(c) 1 kHz and 14 kHz (d) 2 kHz and 14 kHz

3. Consider the signal $x(t)$ shown in figure. Let $h(t)$ denote the impulse response of the **filter matched** to $x(t)$, with $h(t)$ being non-zero only in the interval 0 to 4 sec. The slope of $h(t)$ in the interval $3 < t < 4$ sec is



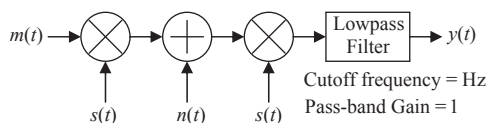
- (a) $1/2 \text{ sec}^{-1}$ (b) -1 sec^{-1}
(c) $-1/2 \text{ sec}^{-1}$ (d) 1 sec^{-1}

4. A message $m(t)$ band-limited to the frequency f_m has a power of P_m . The power of the output signal in the Figure is



- (a) $\frac{P_m \cos \theta}{2}$ (b) $\frac{P_m}{4}$
(c) $\frac{P_m \sin^2 \theta}{4}$ (d) $\frac{P_m \cos^2 \theta}{4}$

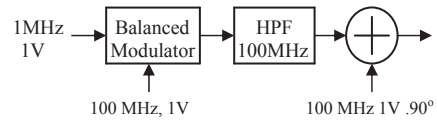
5. In Figure $m(t) = \frac{2 \sin 2\pi t}{t}$, $s(t) = \cos 200\pi t$ and $n(t) = \frac{\sin 199\pi t}{t}$. The output $y(t)$ will be



- (a) $[\sin 2\pi t / t]$
(b) $[\sin 2\pi t / t] + [\sin \pi t / t] \cos 3\pi t$

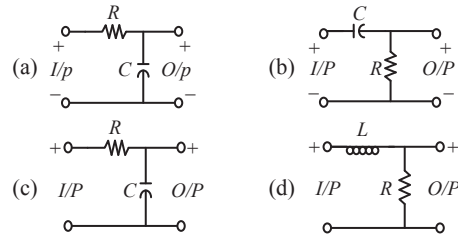
- (c) $[\sin 2\pi t / t] + [\sin 0.5\pi t / t] \cos 1.5\pi t$
(d) $[\sin 2\pi t / t] + [\sin \pi t / t] \cos 0.75 \pi t$

6. A 100 MHz carrier of 1 V amplitude and a 1 MHz modulating signal of 1 V amplitude are fed to a balance modulator. The output of the modulator is passed through an ideal high-pass filter with cut-off frequency of 100 MHz. The output of the filter is added with 100 MHz signal of 1 V amplitude and 90° phase shift as shown in figure. The envelope of the resultant signal is



- (a) Constant
(b) $\sqrt{[1 + \sin(2\pi \times 10^6 t)]}$
(c) $\sqrt{[5/4 - \sin(2\pi \times 10^6 t)]}$
(d) $\sqrt{[5/4 + \cos(2\pi \times 10^6 t)]}$

7. A communication channel has first order low pass transfer function. The channel is used to transmit pulses at a symbol rate greater than the half-power frequency of the low pass function. Which of the networks in Figure can be used to equalize the received pulses?



8. A carrier of frequency 1 MHz is **amplitude modulated** by a signal of frequency 1 KHz to depth of 60 % is passed through a filter of characteristics shown in the given figure I and figure II. If the filter output is fed to an envelope detector, the detector output will be

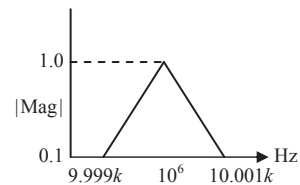


Figure-I

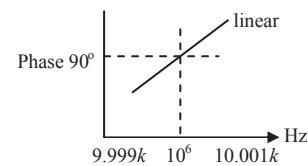
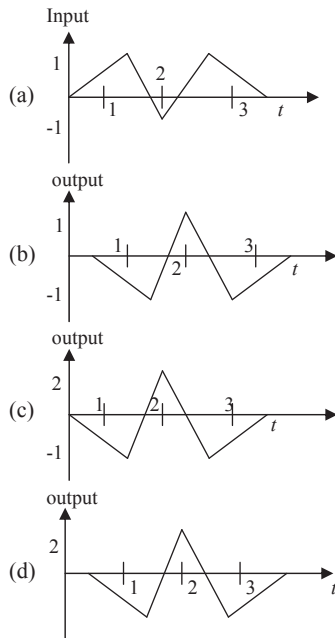
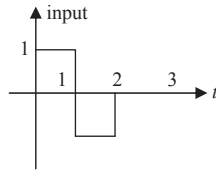


Figure-II

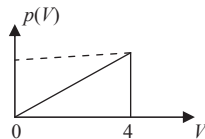
- (a) zero
(b) dc
(c) dc + 1 kHz signal
(d) 1 kHz signal

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9. A signal as shown in the figure is applied to a matched filter. Which of the following does represent the output of this matched filter?

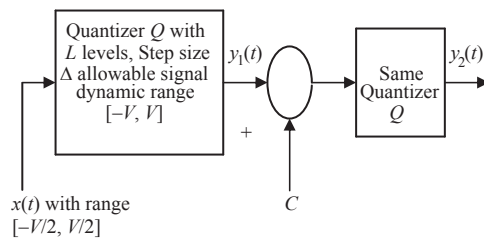


10. An output of a communication channel is a random variable v with the probability density function as shown in the figure the mean square value of v is



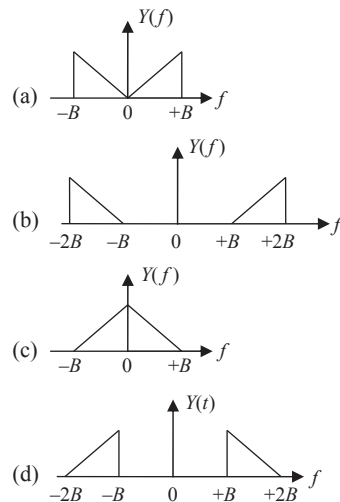
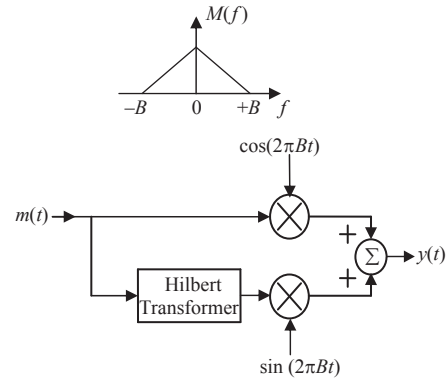
- (a) 4 (b) 6
(c) 8 (d) 9

11. In the following figure value of the constant "C" which is to be added to $y_1(t)$ and $y_2(t)$ are different, is.

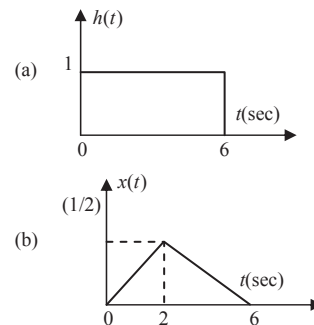


- (a) Δ (b) $\Delta/2$
(c) $\Delta^2/12$ (d) Δ/L

12. In the following scheme, if the spectrum $M(f)$ of $m(t)$ is as shown, then the spectrum $Y(f)$ of $y(t)$ will be

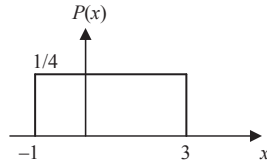


13. The impulse response and the excitation function of a linear time invariant causal system are shown in figure. A and b respectively. The output of the system at $t = 2$ sec, is equal to



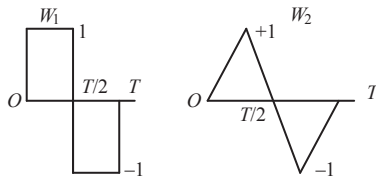
- (a) 0 (b) $1/2$
(c) $(3/2)$ (d) 2

14. For a random variable x following the probability density function, $p(x)$ shown in figure. The mean and the variance are, respectively:



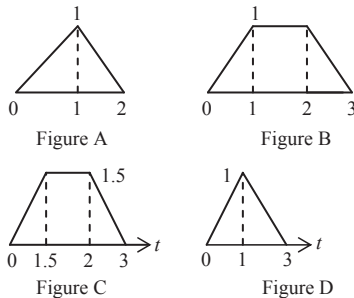
- (a) 1/2 and 2/3 (b) 1 and 4/3
(c) 1 and 2/3 (d) 2 and 4/3

15. One period $(0, T)$ each of two periodic waveforms W_1 and W_2 are shown in figure. The magnitudes of the n th Fourier series coefficients of W_1 and W_2 for $n \geq 1$, n odd, are respectively proportional to



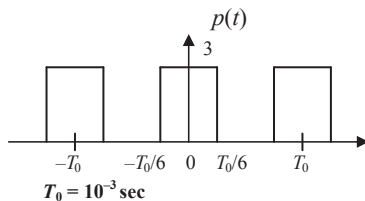
- (a) $|n^{-3}|$ and $|n^{-2}|$ (b) $|n^{-2}|$ and $|n^{-3}|$
(c) $|n^{-1}|$ and $|n^{-2}|$ (d) $|n^{-4}|$ and $|n^{-2}|$

16. Let $u(t)$ be the unit step function. Which of the waveform in figure corresponds to the convolution of $u(t) - u(t - 1)$ with $u(t) - (t - 2)$?



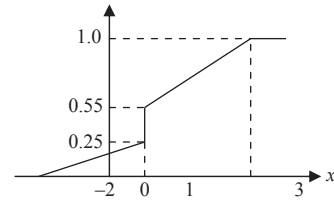
- (a) Figure-A (b) Figure-B
(c) Figure-C (d) Figure-D

17. Let $x(t) = 2 \cos(800 \pi t) + \cos(1400 \pi t)$ is sampled with the rectangular pulse train shown in figure. The only spectral components (in KHz) present in the sampled signal in the frequency range 2.5 kHz to 3.5 KHz are



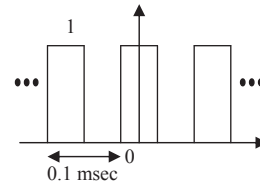
- (a) 2.7, 3.4 (b) 3.3, 3.6
(c) 2.6, 2.7, 3.3, 3.4, 3.6 (d) 2.7, 3.3

18. The distribution function $F_X(x)$ of a random variable X is shown in figure. The probability that $X = 1$ is



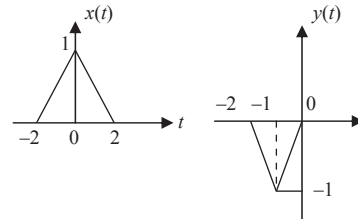
- (a) zero (b) 0.25
(c) 0.55 (d) 0.33

19. A rectangular pulse train $s(t)$ as shown in figure is convolved with the signal $\cos 2(4\pi \times 10^3 t)$. The convolved signal will be a



- (a) DC (b) 12 kHz sinusoid
(c) 8 kHz sinusoid (d) 14 kHz sinusoid

20. Let $x(t)$ and $y(t)$ (With Fourier transforms $X(f)$ and $Y(f)$ respectively) be related as shown in figure



Then $Y(f)$ is

- (a) $-\frac{1}{2} X(f/2) e^{+j2\pi f \cdot 2}$
(b) $-\frac{1}{2} X(f/2) e^{j2\pi f \cdot 2}$
(c) $-X[1/2] e^{j2\pi f \cdot 2}$
(d) None of these

21. The **bandwidth of a 'N' bit binary coded PCM signal** for modulating a signal having bandwidth of ' f ' Hz is

- (a) f/N Hz (b) f/N^2
(c) Nf Hz (d) $N^2 F$ Hz

22. For an AM wave, the maximum voltage was found to be 10 V and the minimum voltage was found to be 5 V. The **modulation index** of the wave would be

- (a) 0.33 (c) 0.52
(d) 0.40 (d) 0.1

23. Generally, a transversal type equalizer with 5 taps can take care of distorted signal due to **inter-symbol interference** in the received signal at

- (a) 4 sampling instants
(b) 5 sampling instants
(c) 9 sampling instants
(d) 0 sampling instants

24. A system has a **receiver noise** resistance of 50Ω . It is connected to an antenna with an input resistance of 50Ω . The **noise figure** of the system is
 (a) 1 (b) 2
 (c) 50 (d) 101
25. A 10 KW carrier is sinus dally modulation by to carrier corresponding to a **modulation index** of 30% and 40% respectively. The total radiated power is
 (a) 11.25 KW (b) 12.5 KW
 (c) 15 KW (d) 17 KW
26. 13 dBm is equivalent to
 (a) 2 mW (b) 20 W
 (c) 20 mW (d) 2 MW
27. 12 signals each band-limited to 5 KHz are to be transmitted over a single channel by **frequency division multiplexing**. If **AM-SSB modulation** guard band of 1 kHz is used, then the bandwidth of the multiplexed signal will be
 (a) 51 kHz (b) 61 kHz
 (c) 71 kHz (d) 81 kHz
28. In a **super heterodyne receiver**, the IF is 455 kHz. If it is tuned to 1200 kHz, the image frequency will be
 (a) 16555 kHz (b) 2110 kHz
 (c) 745 kHz (d) 910 kHz
29. A 6 MHz channel is used by a **digital signalling** system four-level signals. The maximum possible transmission rate is
 (a) 6 M bauds/s (b) 12 M baud/s
 (c) 6 M bits/s (d) 12 M bits/s
30. A 8 kHz communication channel has an SNR of 30 dB. If the channel bandwidth is doubled, keeping the signal power constant, the **SNR** for the modified channel will be
 (a) 27 dB (b) 30
 (c) 33 dB (d) 60 dB
31. The ramp signal $m(t) = at$ is applied to a delta modulator with sampling period T_s step size δ Slope overload distortion would occur if
 (a) $\delta < \alpha$ (b) $\delta > \alpha$
 (c) $\delta < \alpha T_s$ (d) $\delta > \alpha T_s$
32. In a **PCM system**, each quantization level is encoded into 8 bits. The signal to quantization noise is equal to
 (a) $[1/12] \cdot (1/256)^2$ (b) 48 dB
 (c) 64 dB (d) 256 dB
33. In a single error correcting **Hamming code**, the number of message bits in a block is 26. The number of check bits in the block would be
 (a) 3 (b) 2
 (c) 5 (d) 4
34. A signal $m(t) = 5 \cos 2\pi 100t$ frequency modulates a carrier. The resulting FM signal is $10 \cos [(2\pi 10^5 t) + 15 \sin (2\pi 100t)]$ The approximate bandwidth of the FM would be
 (a) 0.1 kHz (b) 1 kHz
 (c) 3.2 kHz (d) 100 kHz
35. Four signals each band-limited to 5 KHz are sampled at twice the Nyquist Rate. The resulting PAM samples are transmitted over a single channel after time division multiplexing. The theoretical minimum transmissions bandwidth of the channel should be equal to
 (a) 5 kHz (b) 20 kHz
 (c) 40 kHz (d) 80 kHz
36. The ratio $[(S/N) \text{ WBFM}] / [(S/N) \text{ AM}]$ for 100% amplitude modulation with identical total transmitted power (m_f is modulation index of FM) is
 (a) $\frac{9}{2} m_f^2$ (b) $\frac{3}{2} m_f^2$
 (c) $\frac{3}{2} m_f^3$ (d) $\frac{9}{2} m_f^3 m_f^3$
37. If the radiated power of AM transmitted is 10 KW, the power in the carrier for modulation index of 0.6 is nearly
 (a) 8.24 kW (b) 8.47 kW
 (c) 9.26 kW (d) 9.6 kW
38. An **angle-modulated** signal is expressed by $f_a(t) = \cos(2 \times 10^8 \pi t + 75 \sin 2 \times 10^3 \pi t)$. The **peak frequency deviation** of the carrier is then
 (a) 1 kHz (b) 7.5 kHz
 (c) 75 kHz (d) 100 MHz
39. For **10-bit PCM system**, the signal to quantization noise ratio is 62 dB. If the number of bits is increased by 2, then the signal to quantization noise ratio will
 (a) increase by 6 dB (b) increase by 12 dB
 (c) decrease by 6 dB (d) decrease by 12 dB
40. For a given data rate the bandwidth β_p of a BPSK signal and the bandwidth β_o of the OOK signal are related as
 (a) $\beta_p = 2\beta_o/4$ (b) $\beta_p = \beta_o$
 (c) $\beta_p = \frac{2\beta_o}{4}$ (d) $\beta_p = \beta_o$
41. A source generates **four equiprobable symbols**. If the source coding is adopted, the average length of code for 100 per cent efficiency is
 (a) 6 bits per symbol (b) 4 bits per symbol
 (c) 3 bits per symbol (d) 2 bits per symbol
42. If the bandwidth of 1th channel is ' w_i ' and the total number of channels accommodated in a time interval of T is ' N ', then the minimum bandwidth ' $B_{\min}$ ' for TDM is equal to
 (a) $N \sum_{i=1}^N w_i$ (b) $\frac{N}{\sum_{i=1}^N w_i}$
 (c) $N \sum_{i=1}^N w_i$ (d) $\frac{1}{\sum_{i=1}^N w_i}$
43. In a DSB-SC system with 100 % modulation, the power saving is
 (a) 50% (b) 66%
 (c) 75% (d) 100%

44. The noise figure of an amplifier is 6 dB. If the input $[S/N]$ ratio is 38 dB, then the output $[S/N]$ ratio will be
 (a) 44 dB (b) 40 dB
 (c) 36 dB (d) 32 dB
45. The output V_R of the ratio detector and the output V_F of similar forester-Seeley discriminator are related as
 (a) $V_F = V_R$ (b) $V_F > V_R$
 (c) $V_F = 0.51 V_R$ (d) $V_F = 2.51 V_R$
46. Without any filtering, a broadcast station at 1600 kHz is heard together with another station at 2500 kHz on a super heterodyne receiver. The IF employed would have been
 (a) 900 kHz (b) 450 kHz
 (c) 300 kHz (d) 25 kHz
47. In a delta modulation scheme, the step height is 75 mV and step width is 1.5 ms. The maximum slope that the staircase can track is
 (a) 50 V/s (b) 55 V/s
 (c) 60 V/s (d) 65 V/s
48. Two signals have the same frequency spectrum but different phase functions. Their power density spectrum will
 (a) Differ in phase (b) differ by $e^{j\omega_0}$
 (c) Differ by ω_0 (d) Be identical
49. In an AM signal when the modulation index is one, the maximum power P_p (where P_c is the carrier power) is equal to
 (a) P_c (b) $1.5 P_c$
 (c) $2 P_c$ (d) $2.5 P_c$
50. In the frequency modulation if f_m is modulation frequency, Δf is maximum frequency deviation and B is bandwidth, then
 (a) $B = \Delta f + f_m$ (b) $B = \Delta f - f_m$
 (c) $B = 2(\Delta f + f_m)$ (d) $B = 2(\Delta f - f_m)$
51. An AM super heterodyne receiver with IF of 455 kHz is tuned to the carrier frequency of 1000 kHz. The image frequency is
 (a) 545 kHz (b) 1 MHz
 (c) 1455 kHz (d) 1910 kHz
52. A 4 GHz amplitude modulated by a low pass signal of maximum cut off frequency 1 MHz. If this signal is to be ideally sampled, the minimum sampling frequency should be nearly
 (a) 4 MHz (b) 4 MHz
 (c) 8 MHz (d) 8 GHz
53. If the modulation index of an AM wave is changed from 0 to 1, the transmitted power
 (a) Increase by 50% (b) Increase by 75%
 (c) Increase by 100% (d) Remains unaffected
54. Let $x(t)$ be a real signal with the Fourier transforms $X(f)$. Let $X^*(f)$ denote the complex conjugate of $X(f)$. Then
 (a) $X(-f) = X^*(f)$ (b) $X(-f) = X(f)$
 (c) $X(-f) = -X(f)$ (d) $X(-f) = -X^*(f)$
55. Let the transfer function of network be $H(f) = |H(f)|e^{j\theta(f)} = 2e^{-j4\pi f}$. If a signal $x(t)$ is applied to such a network, the output $y(t)$ is given by
 (a) $2x(t)$ (b) $x(t-2)$
 (c) $2x(t-2)$ (d) $2x(t-4\pi)$
56. The maximum number of quantized amplitude levels, that a 3-digit ternary PCM system can be used to represent is
 (a) 8 (b) 9
 (c) 27 (d) 81
57. The waveform $A \cos(\omega_1 t + k \cos \omega_2 t)$ is
 (a) Amplitude modulated
 (b) Frequency modulated
 (c) Phase modulated
 (d) Frequency as well as phase modulated
58. Let $x(t) = 5 \cos(50t + \sin 5t)$. Its instantaneous frequency (in rad/s) at $t = 0$ has the value
 (a) 5 (b) 50
 (c) 55 (d) 250
59. An FM wave uses a 2–5 V, 500 Hz modulating frequency and has a modulation index of 50. The deviation is
 (a) 500 Hz (b) 1000 Hz
 (c) 1250 Hz (d) 25000 Hz
60. An MIT radar is operating at the wavelength of 5×10^{-2} m and the pulse repetition frequency (PRF) is 1000. Then the first blind speed (in m/s) occurs at
 (a) 25 (b) 50
 (c) 500 (d) 1000
61. For an AM signal, the bandwidth is 10 kHz and the highest frequency component present is 705 kHz. The carrier frequency used for this AM signal is
 (a) 695 kHz (b) 700 kHz
 (c) 705 kHz (d) 710 kHz
62. In AM, the percentage of total power in sideband is
 (a) 10% (b) 16.67%
 (c) 23.34% (d) 37.5%
63. The detection gain for coherent DSB demodulator is
 (a) 2 (b) 4
 (c) 8 (d) 16
64. Which one of the following statements is correct?
 In PCM, the conditional probability of error is proportional to
 (a) Noise power (N_0) (b) Peak signal energy ($E_{\max}$)
 (c) $\sqrt{N_0}$ (d) $\sqrt{E_{\max}}$
65. For a binary symmetric channel, which one of the following is the correct expression for entropy?
 (p = conditional probability of error)
 (a) $p \log_2(1/p) + (1-p) \log_2\{1/(1-p)\}$
 (b) $p \log_2\{1/(1-p)\} + (1-p) \log_2\{1/p\}$
 (c) $2 \log_2(1/p) + 2 \log_2\{1/(1-p)\}$
 (d) $(1-p)(\log_2(1/P)) + \log_2\{1/(1-p)\}$

66. In amplitude modulation, the modulation envelope has a peak value which is double the unmodulated carrier value. What is the value of the modulation index?
 (a) 25% (b) 30%
 (c) 75% (d) 100%
67. S_i and S_o denote the signal at input and output of linear network. N_i and N_o are the corresponding noises. Which one of the following is the correct expression for noise figure of the network?
 (a) $\frac{S_i S_o}{N_i N_o}$ (b) $\frac{S_o N_i}{S_o N_o}$
 (c) $\frac{S_i N_o}{S_o N_i}$ (d) $\frac{S_o N_o}{S_i N_i}$
68. Which one of the following statements is correct?
 One hundred percent modulation of the carrier for the broadcast FM radio band is achieved when
 (a) Carrier frequency changes by $\pm 100\%$
 (b) Carrier envelope changes by $\pm 100\%$
 (c) Carrier frequency changes by $\pm 75 \text{ kHz}$
 (d) Carrier frequency changes by $\pm 15 \text{ kHz}$
69. Which one of the following represents the Fourier Transform $X(j\omega)$ of the signal $X(t) = t e^{-at} u(t)$?
 (a) $X(j\omega) = \frac{j\omega}{(a + j\omega)}$ (b) $X(j\omega) = \frac{j\omega}{(a + j\omega)^2}$
 (c) $X(j\omega) = \frac{(a + j\omega)^2}{j\omega}$ (d) $X(j\omega) = \frac{1}{(a + j\omega)^2}$
70. An AM voltage signal $s(t)$, with a carrier frequency of 1.15 GHz has complex envelope $g(t) = A_c [1 + m(t)]$, $A_c = 500 \text{ V}$ and the modulation is 1 kHz sinusoidal test tone described by $m(t) = 0.8 \sin(2\pi \times 10^3 t)$, appears across a 50Ω resistive load. What is actual power dissipated in the load?
 (a) 165 kW (b) 82.5 kW
 (c) 3.3 kW (d) 6.6 kW
71. A broadcast AM audio transmitter radiates 125 kW when the modulation percentage is 70. How much of this is carrier power?
 (a) 25 kW (b) 50 kW
 (c) 75 kW (d) 100 kW
72. When a radio receiver is tuned to 555 kHz, its local oscillator provides the mixer with an input at 1010 kHz. At the output another signal is also received along with the desired signal. What is frequency of the other station?
 (a) 910 kHz (b) 355 kHz
 (c) 455 kHz (d) 1465 kHz
73. A given AM broadcast station transmits an average carrier power output of 40 kW and uses a modulation index of sine wave modulation. What is the maximum (peak) amplitude of the output if the antenna is represented by a 50Ω resistive load?
 (a) 50 kV (b) 50 V
 (c) 3.41 kV (d) 28.28 kV
74. A microphone with inbuilt amplifier has an output noise level in a very quiet room of about $30 \mu\text{V rms}$. The maximum output level is about 300 mV rms before severe distortion occurs. What dynamic range does this represent in dB?
 (a) 4 dB (b) 36 dB
 (c) 40 dB (d) 80 dB
75. Analog data having highest harmonic at 30 kHz generated by a sensor has been digitized using 6-level PCM. What will be the rate of digital generated?
 (a) 120 kbps (b) 200 kbps
 (c) 240 kbps (d) 180 kbps

ANSWER KEYS

LEVEL 1

1. (d)	2. (d)	3. (b)	4. (b)	5. (c)	6. (c)	7. (d)	8. (c)	9. (b)	10. (c)
11. (d)	12. (a)	13. (d)	14. (d)	15. (c)	16. (c)	17. (c)	18. (a)	19. (d)	20. (d)
21. (c)	22. (b)	23. (c)	24. (d)	25. (a)	26. (b)	27. (b)	28. (c)	29. (b)	30. (c)
31. (a)	32. (a)	33. (c)	34. (b)	35. (b)	36. (c)	37. (b)	38. (a)	39. (c)	40. (d)
41. (b)	42. (b)	43. (d)	44. (a)	45. (d)	46. (b)	47. (a)	48. (d)	49. (b)	50. (a)
51. (c)	52. (a)	53. (a)	54. (b)	55. (c)	56. (a)	57. (a)	58. (d)	59. (b)	60. (b)
61. (b)	62. (a)	63. (d)	64. (a)	65. (d)	66. (d)	67. (b)	68. (a)	69. (d)	70. (d)
71. (d)	72. (c)	73. (b)	74. (b)	75. (a)					

LEVEL 2

1. (b)	2. (a)	3. (b)	4. (d)	5. (b)	6. (b)	7. (b)	8. (d)	9. (c)	10. (a)
11. (c)	12. (b)	13. (c)	14. (c)	15. (b)	16. (d)	17. (b)	18. (a)	19. (c)	20. (c)
21. (b)	22. (b)	23. (a)	24. (b)	25. (c)	26. (d)	27. (d)	28. (b)	29. (d)	30. (c)
31. (b)	32. (c)	33. (c)	34. (a)	35. (c)	36. (d)	37. (b)	38. (b)	39. (a)	40. (b)
41. (a)	42. (a)	43. (a)	44. (c)	45. (b)	46. (c)	47. (d)	48. (d)	49. (a)	50. (c)
51. (b)	52. (b)	53. (d)	54. (b)	55. (c)	56. (a)	57. (d)	58. (d)	59. (c)	60. (a)
61. (b)	62. (d)	63. (b)	64. (b)	65. (a)	66. (a)	67. (b)	68. (b)	69. (a)	70. (c)
71. (b)	72. (a)	73. (a)	74. (c)	75. (d)					

LEVEL 3

1. (b)	2. (b)	3. (b)	4. (d)	5. (c)	6. (c)	7. (b)	8. (c)	9. (c)	10. (c)
11. (c)	12. (a)	13. (b)	14. (b)	15. (c)	16. (b)	17. (a)	18. (b)	19. (d)	20. (b)
21. (c)	22. (a)	23. (a)	24. (b)	25. (a)	26. (c)	27. (c)	28. (b)	29. (d)	30. (c)
31. (d)	32. (b)	33. (c)	34. (c)	35. (d)	36. (a)	37. (b)	38. (c)	39. (b)	40. (d)
41. (d)	42. (c)	43. (b)	44. (d)	45. (b)	46. (b)	47. (a)	48. (d)	49. (b)	50. (c)
51. (d)	52. (d)	53. (a)	54. (a)	55. (c)	56. (c)	57. (d)	58. (c)	59. (d)	60. (a)
61. (b)	62. (b)	63. (a)	64. (d)	65. (a)	66. (d)	67. (c)	68. (a)	69. (d)	70. (c)
71. (d)	72. (d)	73. (c)	74. (d)	75. (d)					

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CHAPTER

MICROWAVE

ENGINEERING

11.1 MICROWAVE TUBES

There are three broad categories of microwave tubes, namely:

- Microwave triodes.
- Klystron type tubes characterized by brief, though sometimes repeated, interaction between an electron beam and an RF voltage.
- Microwave tubes involving continuous interaction of an electron beam and RF field. The main members of this group are traveling wave tube (TWT), Backward wave oscillator (BWO), Magnetron and cross field Amplifier (CFA).

Microwave Triodes

In general, vacuum tubes suffer from the problems of inter electrode capacitances and electrode lead inductances when used at microwave frequencies. Transit time becoming a significant part of the signal time period is another serious problem.

Two Cavity Klystron Amplifier

A two cavity klystron tube makes use of the *transit time effect* for its operation. It is a two cavity klyon tube. A high velocity electron beam is formed and focussed and then sent down a long glass tube. The beam passes a gap in the buncher cavity. The RF signal to be amplified is applied to the buncher cavity. The beam is allowed to drift freely till it reaches another gap in the catcher cavity. *Oscillations are excited in the catcher cavity.* The power of these oscillations is much higher than that in the buncher cavity. The drift space is pretty long and the transit time in this space is made use to form electron bunches. The gaps must be so small that the voltage across them does not change significantly during the passage of a certain bunch of electrons.

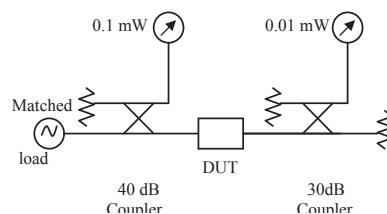


Fig. 11.1

Bunching occurs only once per cycle centred around the reference electron. With proper design a little RF power input to buncher result large current at catcher with considerable gain.

Reflex klystron

Reflex klystron is a klystron like microwave tube with *only one cavity* and a *repeller electrode*. The repeller electrode with a very high negative potential provides the feedback and converts the tube into an *oscillator*. Reflex klystron is a low efficiency, low power microwave oscillator. The operation of reflex klystron also makes use of transit time effects.

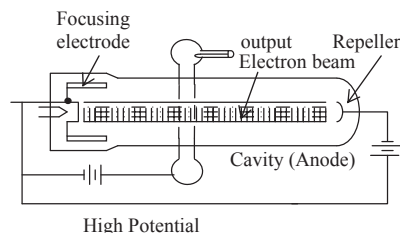


Fig. 11.2

Magnetron

Magnetron is a microwave oscillator capable of producing *high peak power oscillations*. It comprises of a cylindrical cathode surrounded by an anode structure with multiple cavities. It makes use of *interaction of a radial electric field* and an *axial magnetic*

field to produce oscillations of high peak power. The magnetic field is perpendicular to the plane of the radial electric field, a magnetron is also referred to as a cross, *field device*. The output in a magnetron is taken from one of the cavities by means of a coaxial line. The magnetron due to a large number of cavities has a *number of resonant frequencies and modes of oscillation*. Eight cavity magnetron is usually used in practice. For such a magnetron, for self consistent oscillations, the *phase difference* between adjoining anode poles is $(n\pi/4)$.

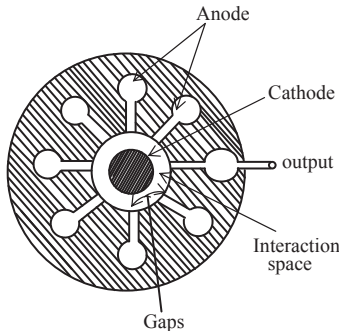


Fig. 11.3

where (n) is an integer, *Strapping* is used to avoid mode jumping in magnetrons having identical cavities.

To avoid difficulties with strapping at high frequencies rising sun cavity structure is used in magnetron.

Travelling Wave Tube (TWT)

A travelling wave tube is basically a *microwave amplifier* like a klystron. However, it differs from a klystron in the sense that here the interaction between the electron beam and the RF field is continuous. TWT is capable of providing very *large bandwidth*. It can be used as a medium of high power pulses or CW microwave amplifier. A narrow electron beam is sent through the center of a long axial helix which is made positive with respect to the cathode. The collector is made more positive with respect to the helix. The beam acquires a high velocity. The RF signal is applied to the input end of the helix. This field *propagates around the helix with a speed equal to velocity of light* in the free space. The axial velocity of this electric field is *however equal to the electron beam velocity*. The axial RF field and the electron beam interact continuously. The electron beam bunching gives energy to the field. The interaction between the beam and the RF field is similar to that of magnetron.

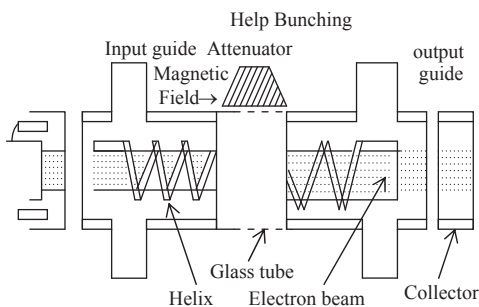


Fig. 11.4

The low power, low noise TWTs are used in radars and other microwave receivers. Medium and high power TWTs are used for communication and radar. The majority of space borne power output amplifiers have been TWTs because of their *high reliability, high gain and large bandwidth*. Majority of satellite earth stations use TWTs as output tubes.

11.2 SOLID STATE DEVICES

Semiconductor Microwave Devices

Varactor Diodes: A Varactor Diode is a semiconductor junction diode whose property of a *variable junction capacitance* as a function of the *reverse biased voltage* is made use of for the purpose of *tuning in microwave frequency multipliers*. They are also used in *low noise parametric amplifiers*.

A Step Recovery Diode

It is similar to a varactor in construction. It *stores charge* when it is conducting with a forward bias, it *generates a current pulse rich in harmonics* when it is made to discharge by applying a reverse bias. It is also referred to as snap-off varactor. The snap-off time should be less than the reciprocal of the desired output frequency. For an output frequency of 10 GHz. The snap off time has to be less than 100 ps.

Typical snap off time range for step recovery diodes is 100 ps to 1000 ps.

Tunnel Diodes

A tunnel diode is a *voltage* controllable, negative resistance device having *I-V characteristics* expresses by *single valued function of voltage*. It is a junction diode with a very thin junction which exhibits negative resistance at a **low forward bias**. It is used as a microwave amplifier or oscillator. They are usually used as moderate to *low noise preamplifiers* in all kinds of microwave receivers upto a frequency range of 50 GHz.

Gunn Diodes

The Gunn diodes make use of the *Transferred Electron Effect* in bulk semiconductor materials. This effect is present in Gallium Arsenide, Indium Phosphide, Cadmium Telluride and Indium Arsenide. The effect is instrumental in **generation of microwave oscillations** in Gunn diodes differ from the other semiconductor diodes in the sense that they depend for their operation on the bulk properties of the semiconductor material rather than its junction properties. It is also a negative resistance device. The *V-1 characteristics* of a Gunn diode are very similar to those of tunnel diodes, but of course for vastly different reasons.

IMPATT Diode

IMPATT diodes also do not depend for their operation on the junction properties. They *depend upon the controlled avalanche effects*. The word IMPATT infect stands for IMP

act Avalanche and Transit Time. It exhibits negative resistance, the AC negative resistance which may be defined as the *voltage across the diode being 180° out of phase with the current flowing through it*. This is the kind of negative resistance experienced in IMPATT diodes. IMPATT diodes are made from silicon or Gallium, Arsenide or even indium Phosphide. Silicon IMPATT diodes can be used in excess of 200 GHz. IMPATT diodes are used as *microwave amplifiers and oscillators*. The noise is the biggest problem with IMPATT diodes.

TRAPATT Diodes

The word TRAPATT stands for Trapped plasma Avalanche Triggered Transit. A Trapatt diode is very similar to an IMPATT and is only a different method of operating the IMPATT diode. It is also a negative resistance device capable of producing *high pulse microwave powers* at relatively lower frequencies.

Microwave Circuits

Parametric Amplifiers: Parametric amplifiers are used for *low noise amplification* at microwave frequencies. A parametric amplifier is low noise as it *does not involve any resistance* in the amplifying process. It makes use of a device whose *reactance is varied* in such a manner as to yield amplification. Varactors are commonly used as the active device.

In narrowband parametric amplifiers, a varactor diode forms a part of the tuned circuit and in a *wideband* parametric amplifier, a number of diodes are used as part of traveling wave structure. Both types can be either degenerate or non-degenerate.

11.3 MICROWAVE GENERATION AND AMPLIFIER

Parametric Amplifier

This system is called parametric amplifier because the principal requires variation of a parameter of a tuned circuit.

Principal

Vary the capacitance of a condenser by varying the spacing between the plates, since capacitance is inversely proportional to the spacing.

$$\omega_i = \omega_p - \omega_s$$

ω_i = idler frequency [if the pump frequency depart from twice the signal frequency we obtain a beat frequency called idler frequency.

$$\omega_p = \text{pump frequency}$$

$$\omega_s = \text{signal frequency}$$

- $\omega_p \gg \omega_s$ up converter: highly stable wide Bandwidth and low gain.
- $\omega_p < \omega_s$ down converter, no gain.

Cross Field Amplifier

The cross field amplifier (CFA) is a microwave power amplifier similar to a magnetron. It makes use of a magnetron structure to provide an interaction between crossed DC electric and magnetic fields on one hand and RF field on the other. Like a TWT it uses a slow wave structure to provide interaction between the electron beam and a moving RF field.

Backward Wave Oscillators

A Backward Wave Oscillator (BWO) is a CW microwave oscillator with a very *large tuning range*. It operates on TWT principles of using a helix like slow wave structure to provide electron beam–RF field interaction.

11.4 WAVEGUIDE

- Waves are guided in hollow rectangular or circular tubes and tubes called as wave-guides.
- Size of waveguides become very large at low frequencies, so waveguides are used at very high frequencies.
- Air as dielectric, the dielectric loss is minimum as compared to dielectric filled co-axial cables.
- Wave guides can transmit more power than a co-axial cable.
- Simpler to construct and more rugged.
- It can also be used as circuit element, like that of transmission lines.
- Wave guide are used at very high frequency, called as Microwave from 1 GHz to 1000 GHz.

Important	
Band	Frequency (GHz)
HF	0.003 to 0.03
VHF	0.03 to 0.3
UHF	0.3 to 1
L	1 to 2
S	2 to 4
C	4 to 8
X	8 to 12
Ku	12 to 18
K	18 to 27
Ka	27 to 40
millimetre	40 to 300
submillimetre	> 300

Cut-off Wave Length

$$\lambda_c = \frac{1}{\sqrt{\frac{m^2}{2a^2} + \frac{n^2}{2b^2}}}$$

(m, n) are integer and a, b are dimension of wave guide).

- TE wave (Transverse electric mode): For TE mode there is no electric field in the direction of propagation.
- TM wave (Transverse magnetic mode): For TM mode then is no magnetic field in the direction of propagation.
- TEM wave (Transverse electric and magnetic mode): Electric and magnetic fields are mutually perpendicular and no field component in the direction of propagation.
- Only those frequencies above the cut-off will propagate in the waveguide.
- Dominant mode is that which gives lowest frequency of propagation.

• Phase velocity $= \frac{C}{\sqrt{1 - (f_c/f)^2}}$

$$f_c = \frac{1}{2\sqrt{\mu\epsilon}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

- Wave guide impedance

$$Z_w = \frac{\omega\mu}{\beta\omega} = \frac{\omega\mu}{\sqrt{\mu\epsilon}\sqrt{1 - (f_c/f)^2}} \sqrt{\frac{\mu}{\epsilon}} \times \frac{1}{\sqrt{1 - (f_c/f)^2}}$$

$$Z_w = \frac{\eta}{1 - (f_c/f)^2}$$

where η = intrinsic impedance of dielectric
 $= 120\pi$ or 377 for free space.

$$Z_w = \eta - \frac{\lambda_g}{\Lambda}$$

$$\text{For } TM_{nm} \quad Z_w = \eta \left(1 - (f_c/f)^2\right) = \eta \frac{\lambda}{\lambda_g}$$

- As $(f/f_c) < 1$; Z_w for TE wave is always greater than η and for TM, is it always less than η .

Power Transmission in Rectangular Waveguides

- For TM_{mn} mode, average power transmitted through the rectangular waveguide is

$$P_{av} = \sqrt{\frac{1 - (f_c/f)^2}{2\eta}} \int_0^a \int_0^b (|E_x|^2 + |E_y|^2) dx dy$$

- For circular waveguides basic difference between TE and TM is that n can be zero for TM but not for TE.

When $n = 0$, in TM, E_θ, H_r vanish leaving E_r, H_θ whereas in TE all vectors vanish

So TMM $n; m, n$, from 0, 1, 2--- etc.

TEM $n; n \neq 0, m = 0, 1, 2$ --- etc.

- TEM modes in circular waveguides: Both electric and magnetic field is zero in direction along the propagation.
- Cut-off frequency is zero.

For TE_{10} mode;

$$P_{av} = \frac{E_0^2}{4} \frac{\beta}{\omega\mu_0} (ab)$$

where E_0 = peak value of electric field.

- Lower order non-trivial mode for TM is TM_{11} .

11.5 MICROWAVE COMPONENTS AND CIRCUITS

Microwave Component

Cavity resonators-entrant cavities slow wave structure, tees, directional coupler, isolators and circulators these passive devices may form part of active such as Klystrons, Magnetrons and Travelling Wave tubes (TWTs).

Cavity Resonators

Cavity resonators are metallic enclosures that confine the electromagnetic energy within it.

The magnetic and electric energies of the wave constitute the inductance and capacitance and finite conductivity of the wall as the resistance.

Rectangular Cavity Resonators

These are closed hollow rectangular metallic boxes with silvered inner wall's for high conductivity and Q .

Re-entrant Cavities

A re-entrant cavity is one whose metallic boundaries extend into the interior of the cavity.

There will be infinite of resonant frequencies or modes of oscillation.

Hybrid Circuits

- For transmission of microwave energy, branch lines have to be connected to a main waveguide without loss of power and preserving the waveguide mode in the main waveguide.
- As in microwave energy is transported by EM waves and not by voltage or current, special coupling component have to be used.
- Such component are called tees. Some of them are E-plane tee, H-plane tee, hybrid rings, corners, twist.

Waveguide Junctions

Waveguide junctions are used whenever it is desired to combine two or more signals into one or split a signal into two or more

component in a Waveguide system. The commonly used Waveguide junctions include (1) T-junction and (2) Hybrid junctions. E plane tee junction and H plane tee junction are the two popular tee junctions. In an E-plane tee, all the three arms lie in the plane of the electric field. All the three arms of an H-plane tee lie in the plane of the magnetic field.

Waveguide Diaphragm/Apertures/Irises

Waveguide diaphragms or Apertures or irises are used to provide impedance matching in Wave guides in the same way as we used stubs in the case of transmission lines. The diaphragms may be capacitive, inductive or resonant. Diaphragms are difficult to adjust with the result that they are normally used to correct permanent impedance mismatches only.

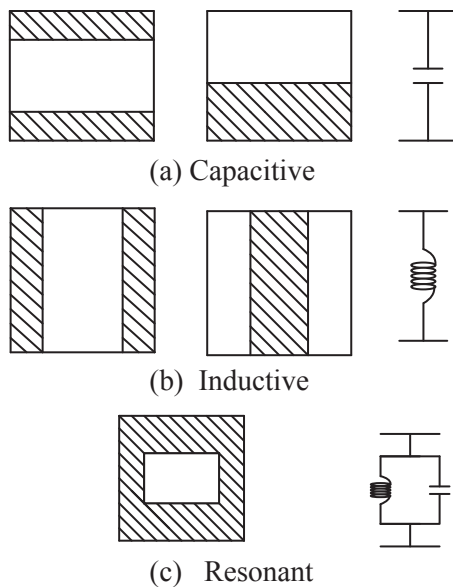


Fig. 11.5

Waveguide Posts

Waveguide posts are also used for impedance matching. A cylindrical post extending into the waveguide from one of the two broad sides has the effect of providing a lumped reactance at that point. The reactance provided by the post may be inductive or capacitive depending upon how far it extends into the Waveguide. Posts are easier to adjust as compared to diaphragms.

Cavity Resonators

A cavity resonator is a section of a waveguide closed off at both ends with metallic planes. Cavity resonators are used as tuned circuits at microwave frequencies. The simple cavity resonator shapes such as Spheres, Cylinders or Rectangular prisms are not often used. They suffer from a disadvantage that their resonant frequencies are harmonically related and it is a serious drawback in situations where pulses of energy are fed to cavity.

Directional Couplers

Waveguide Directional Couplers, like Transmission Line Directional Couplers, are mainly used for unidirectional power flow measurement and SWR measurement. Waveguide directional coupler which is nothing but an analog of the transmission line coupler.

Isolators and Circulators

Isolators and Circulators are used at microwave frequencies to provide isolation. It is important in majority of the applications at microwave frequencies that the coupling is a unidirectional affair. This, for instance, applies to most of the microwave generators. Where the output amplitude and frequency could be affected by changes in load impedance.

Duplexers

A duplexer is a device that allows the use of a common antenna for both transmission and reception by isolating the transmitter and receiver from each other.

E-Plane Tee

In this, the electric is parallel to the side or tee arm's axis:

- If TE_{10} input is applied to side arm at part-3 the output at part-1 and part-2 will be equal but in opposite phase.
- The resultant field leaving the junction through the tee-arm-3 is proportional to the difference between the instantaneous fields entering from part 1 and 2 of the main arm. If the field entering are in phase, output is nil and if out of phase, then output is doubled.

H-plane Tee

If waves are fed into part-1 and part-2 the output at part-3 is in phase and additive if the input is fed into part-3 the output at 1 and 2 is split equally in phase and magnitude.

Hybrid Tee or Magic Tee

This is combination of E-plane tee and H-plane tee.

Directional Couplers

They are microwave junction, which receive energy from two or more sources and transmit them to two or more outlets. A four port directional coupler shown below:

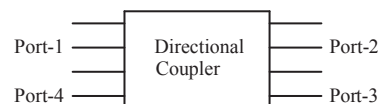


Fig. 11.6

11.6 ■ Microwave Engineering

- If the waveguide are terminated in their characteristic impedance, power from 1 flows to 2, from 3 to 4, without reflection no source of coupling from 1 to 3 and 2 to 4.
- Coupling factor for power fed into port-1

$$10 \log_{10} \left(\frac{p_1}{p_4} \right)$$

p_1 = power in main port-1

p_4 = power in main port-4

Directivity (dB) =

$$\frac{\text{Power in secondary port-4}}{\text{Power in secondary port-3}} = 10 \log \frac{p_1}{p_3}$$

- S-matrix for directional couplers:

$$S = \begin{bmatrix} 0 & s_{12} & 0 & s_{14} \\ s_{21} & 0 & s_{23} & 0 \\ 0 & s_{32} & 0 & s_{34} \\ s_{41} & 0 & s_{43} & 0 \end{bmatrix}$$

Different Type of Directional Couplers

1. Two hole directional coupler
 2. Four hole directional coupler
 3. Reverse coupling
 4. Loop directional coupler
- A better method of impedance matching is by providing thin metallic plates to a waveguides. This is called iris or window.
 - Insertion of iris is equivalent with their edges parallel to the electric field, called as inductive. This is equivalent to shorted stub with $l < \lambda/4$.

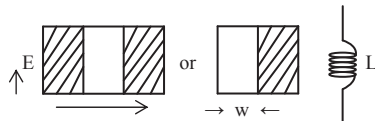


Fig. 11.7

If the edge or the window is parallel to magnetic field it acts as a capacitor.

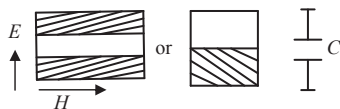


Fig. 11.8

If a rectangular iris with an opening in the center is placed in the waveguide, it functions as a parallel tuned circuit.



Fig. 11.9

Realises shunt connected series resonant circuit.

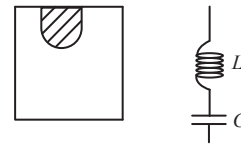


Fig. 11.10

Shunt Resistance

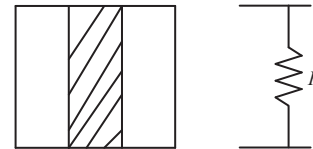


Fig. 11.11

11.6 MICROSTRIP CIRCUIT

Striplines and microstrips are also conducting media developed as an alternative to waveguides for applications that require *miniaturization*. Stripline evolved from a coaxial line. Propagation in a stripline is by means of a unipure *TEM mode*. Microstrip is analogous to a parallel wire line. Semiconductor microwave devices are often packaged, so that they can be directly connected to a stripline or microstrip. It has dielectric, ohmic and radiation losses.

Saw Devices

Saw devices make use of *propagation of surface acoustic waves* on the surface of a solid piezoelectric material. The commonly used piezoelectric materials are Quartz and lithium Niobate.

11.7 MICROWAVE ANTENNA

Microwave antennas are highly directional because they are required in direction finding equipment such as radar etc.

Microwave antennas are smaller in size because of the small length of the waves and so the small antenna size is several times the wavelength of the microwaves.

Horn Antennas

An open ended waveguide is capable of radiating just like an antenna, into open space, if it is suitably excited at one end and opened at the other. To overcome reflected back power due to mismatch the mouth of the open end is flared, so that it takes the shape of a Horn and so it is called Horn antenna. Changing over to Horn from open ended waveguide increases the directivity and also the diffraction is reduced.

The radiation pattern of an antenna using a parabolic reflector has a very sharp main lobe and surrounding the main lobe are minor lobes which are very small in size as compared to the main lobe. If the primary or feed antenna is non-directional then the paraboloid produces a beam of radiation whose width is given by

$$\varphi = \frac{70 \lambda}{D} \text{ and } \varphi_0 = 2\varphi$$

where D = mouth diameter of reflector

φ = beam width, between half power points, in degrees.

φ_0 = beam width between null, in degrees.

In the above equations it is assumed that the feed antenna used are omnidirectional and therefore the reflector is uniformly illuminated which is very difficult to attain in practice.

The maximum gain of an antenna using a uniformly illuminated paraboloid reflector is given by

$$A_p = 6 \left(\frac{D}{\lambda} \right)^2$$

where, A_p = power gain with respect to a resonant half wave dipole.

If the intensity of illumination at the reflector falls off at the edges, then power gain will be

$$A'_p = 4.2 \left(\frac{D}{\lambda} \right)^2$$

It can be proved through numerical examples that very large gains and narrow beam widths are obtainable with paraboloid reflector. In order to be fully effective and useful a paraboloid must have a mouth diameter of at least 10 λ ; and this is the reason why paraboloid reflectors are not used for the lower frequencies i.e., for VHF in the band where television broadcasting is done e.g., a television channel operating at 65 MHz would require a reflector of at least 46.2 m.

Lens Antenna

The Lens antenna is yet another optical principle that can be applied to microwaves. It is used as a collimator at frequency greater than 3 GHz and works just like a glass lens in optics.

11.8 MICROWAVE MEASUREMENT

In microwave, measurements of the following quantities are made to determine and monitor the functioning of the system.

Power

Power cannot be measured at microwave similar to the practice at low frequencies of measuring voltage and current as the energy is propagated in the form of waves and not conducted, Low power is measured in a bolometre and high power by water calorimetre.

Measurement of low power

In a **bolometre**, the measuring elements *undergoes a changes in resistance* due to heating on absorption of power. The change in resistance may be positive as normally in any element i.e., barraters or negative as in thermostats. Sensitivity of positive resistance types called barraters is 5.2 ohms/mW and thermistic semiconductor type, 60 ohms/m W.

Bridge Method

The bolometre forms one arm of the bridge and receives the radiation from the microwave to be measured. The bridge goes out of balance and bolometre resistance changes. DC power is fed to the bridge until balance is restored as read from galvanometre. The power may be calculated from measurement of current and voltage or the galvanometre may be calibrated in terms of power.

Measurement of High Power

Calorimetre is connected as a method termination to a waveguide system. Heat energy $H = ms \theta$

m : mass calculated from rate of flow of water through the calorimetre.

S = specific heat

q = temperature rise,

Water is circulated at measured rate through the load which absorbs the microwave power and temperature rise is measured by the difference in inlet and outlet temperature. In this method, powers less than 5 W cannot be measured.

Frequency Variable Length Cavity Resonator

A typical cavity resonator used as wave metre is shown. The cavity is mounted with its axis perpendicular to the main waveguide and is coupled to the guide through the Iris which is adjustable with the help of the plunger which varies the length of the cavity to produce different resonant frequencies.

A block of poly iron dielectric absorbing material on the back of the plunger prevents resonance in the back cavity.

By proper design, the cavity can be used as wave metre indicating different frequencies directly on the micrometre head attached to the plunger.

Transmission Type Wave Metre

The cavity resonator can be E-plane Tee connected in series with the generator:

Maximum energy reaches the load, when the cavity is tuned for resonance. The waveguide at the output of the wave metre is coupled to a detector which shows maximum output only when the cavity, is resonant to the line frequency, that is the generator frequency. The frequency may be read off the micrometre on the plunger of the waveguide used fortuning the cavity to the generator frequency.

Absorption Type Wave Metre

The 'neck' d is made approximately half a guide wavelength $\left(\frac{\lambda_g}{2}\right)$, so that an effective short-circuit appears at the waveguide when the cavity is off resonance, and there is a high impedance of the rejecter circuit at waveguide, at resonance.

The waveguide is effectively in series with the load, dip in the load power occurs as the wave metre is tuned through resonance. The magnitude of the dip is a function of the cavity Q which is very high and we can get a critical dip, to clearly indicate resonance. Where the frequency is less than 3000 MHz or 3GHz coaxial type wave metre is in used.

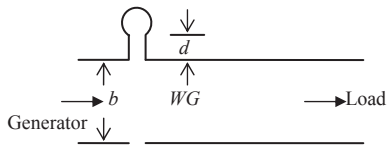


Fig. 11.12

Coaxial Line Resonator Wave Metre

In this system device, there are two coupling loops. One is connected to detector. The other is loosely coupled to the system under observation through a section of the coaxial line.

The relative positions of the loops are such that there is no direct coupling between them. The detector gets input only when the resonator is tuned to resonance. The difference in the readings of the micrometres one the plunged heads for maximum reading multiplied by two gives the wavelength.

The coaxial line wave metre can be used both transmission type wave metre or absorption type wave metre.

Phase

As a phase change of 2π radians or 360° corresponds to one wavelength, phase can be measured by electrical length at microwave frequencies. The electrical length of a standard waveguide is measured and in the place of the waveguide, the device is inserted and its electrical length measured from difference in electrical length, the phase can be calculated. The physical lengths of the standard waveguide and the unknown device should be same.

Voltage Standing Wave Ratio

From transmission line theory we know that waveguide must also be terminated by its characteristic impedance for lossless transfer of power. Termination by any other impedance will cause reflection of voltage and current from the receiving end. This causes not only loss of power but sets up voltage antinodes which may cause breakdown of waveguide must be terminated by its characteristic impedance.

This is known as 'impedance matching' a measure of the correct impedance matching is the VSWR (Voltage Standing Wave

Ratio). It may be current also, ISWR. As it is easier to measure voltage across a line at any point, it is generally specified as VSWR. It is defined as:

$$VSWR = \frac{V_{\max}}{V_{\min}} = \frac{I_{\max}}{I_{\min}} = S$$

$$= \frac{V_1 + V_R}{V_1 - V_R} = \frac{1 + \frac{V_R}{V_1}}{1 - \frac{V_R}{V_1}} = \frac{1 + \Gamma}{1 - \Gamma}$$

$$\Gamma, \text{ the Reflection coefficient} = \frac{V_R}{V_1}$$

$$= \frac{\text{Amplitude of reflected wave}}{\text{Amplitude of incident wave}}$$

$$\text{Also, } \Gamma = \frac{S - 1}{S + 1}$$

VSWR varies from 1 when perfectly matched.

($V_R = 0$) to Γ at maximum mismatch, i.e., when $V_R = V_1$ and

$\Gamma = 1$. This happens when the line is open or short circuited.

Measurement of Q

$$Q = \frac{f_r}{BW}$$

In the experiment on VSWR, the point of voltage minimum is the resonant frequency f_r . Bandwidth (BW) is between the two half power points Q can be calculated from equation (above). Q is calculated of resonant cavities which are very high, of the order of thousands.

Noise Bandwidth (B)

B is the width in Hz of a rectangular response curve that has the same area as the actual response curve of the network under test. And the height of which is the same as the height of the actual response curve at a specific frequency f_0 . The reference frequency f_0 is usually taken as the frequency at which response is maximum.

The signal generator (with an impedance at output equal to that of the noise source to which the network is connected) is used for the measurement. The noise power is read by a power noise measuring device like Bolometre bridge. *Diode detectors or other non-linear power measuring devices should not be used.*

11.9 MASERS AND LASERS

Maser (Microwave amplification by Stimulated Emission of Radiation) Provides extremely low noise microwave amplification. The basic principle of operation of a Maser is the following: Certain materials have atomic systems

that can be made to resonate magnetically at frequencies depending upon the atomic structure of the material and the strength of applied magnetic field. Resonant absorption takes place when such a resonance is stimulated by an external signal at the frequency. If the material is suitably excited or pumped from another source, emissions will occur. The materials used could be gaseous such as Ammonia or solid state such as Ruby. Ruby maser is the more practical master amplifier. Noise figures of a fraction dB are common in masers.

Lasers

The laser is a source of coherent electromagnetic waves at infrared and light frequencies. It operates on principles similar or those of the maser, and indeed an understanding of the maser is virtually a prerequisite to the understanding of its more spectacular staminate. However, the frequencies are much higher; for visible light, these range from 430 to 750 terahertz (THz) (i.e., 430,00 to 750,000 GHz!). It can thus be seen that the scope and information-carrying capacity of lasers is immense.

Lasers and Their Communications Applications

Non-communications applications of lasers often make the news. They include distance and speed measuring equipment, industrial welding, etching (fine enough for the manufacture of integrated circuits) and occasional illuminations of a ludicrously small area of the moon with an Earth operated laser. Everyone has heard of the three dimensional holograms possible with lasers, while other lasers have been used in optical and other surgery, and still others suggested for military uses. Each of these is a valid laser application, but none of them falls into the category of communications applications.

Semiconductor lasers

It is capable of producing laser action. This occurs when the diode is forward biased, so that effective dc pumping is needed (a very convenient state of affairs). Depending on its precise chemical composition, the GaAs laser is capable of producing an output within the range of 0.75 to 0.9 μm , i.e., in the near infrared region (light occupies the 0.39 to 0.77 μm range).

11.10 MICROWAVE PROPAGATION

Space Wave Propagation accounts for all microwaves communication. It employs line of sight communication. It becomes essential in V.H.F and U.H.F. band because the ground wave system attenuates the energy to negligible amplitude within a few hundred feet while the ionosphere is not able to refract any energy to the earth.

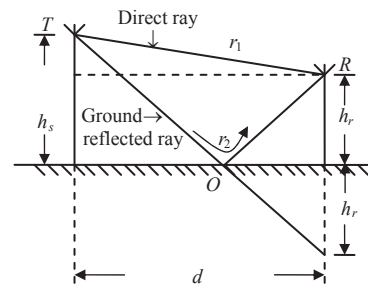


Fig. 11.13 Direct and indirect paths by which energy travels from a transmitting antenna to a receiving antenna

The field strength at the receiving antenna R can be expressed as

$$E_r = \frac{2E_o}{d} \frac{\sin 2\pi h_s h_r}{\lambda d}$$

where E_o = Field intensity at a unit distance by the transmitting antenna in the desired direction.

$$E_r = \frac{2E_o}{d} \times \frac{2\pi h_s h_r}{\lambda d} = \frac{4\pi h_s h_r}{\lambda d^2} \cdot E_o$$

Increasing the quantity $\frac{h_s h_r}{\lambda}$ results in an increase in the field strength at large distances; since the oscillation in the amplitude now occur more rapidly with increasing distance. Further, the distance d' at which the field strength is always less than the free space value, is greater than the value for the previous case. This is explicitly shown in figure. An increase in the quantity $\frac{h_s h_r}{\lambda}$ can be achieved by increasing the antenna heights or the frequency.

Various Other Considerations in Space Wave Propagation

Effect of earth imperfections and roughness on field strength in the interference zone:

The finite conductivity and dielectric constant of the earth cause magnitude of the reflection coefficient to be less than one and phase shift to differ by 180 degrees. The field strength at point R is still the vector sum of the direct and ground reflection waves, but because now the ground reflected ray has less amplitude than the direct ray, it causes the field strength to vary. The nulls are field into a great extent, while the field strength at large distance is increased.

Duct Propagation

The energy represented by the rays which lie within the angular range angle q about the horizontal gets trapped within the duct. The angle q is typically of the order of 1° or less.

Duct propagation can also be viewed as wave propagation in a waveguide. The top is represented by the height of the

minimum in the M curve. It is leaky and allows some energy within the duct to escape to the space above the duct (guide).

Because of the waveguide phenomena. There exists a cut-off frequency. The tendency of the energy to leak increases with the increases in ratio λ/h' , which is ratio of wavelength to the duct height. If the ratio i.e., λ/h' exceeds a certain critical value, the duct effect completely disappears. This gives rise to a maximum wavelength $\lambda_{\max}$ which can be utilized for duct propagation, and is given by

$$\lambda_{\max} = 2.5 h' \sqrt{\Delta M \times 10^{-6}}.$$

Here ΔM is the total decreases in value of M when going from bottom to the top of the duct.

11.11 MICROWAVE COMMUNICATION SYSTEMS TERRESTRIAL AND SATELLITE BASED

Microwave travels in straight line and, therefore, they must travel between point which are with in sight of each other. Thus for distances that extend beyond the horizon, we need several repeaters to relay the waves from point to point.

The normal distances between two repeaters is 50–80 km. This poses no problem on land.

Microwave link

A microwave link performs the same functions as a copper of optic fiber by using point to point microwave transmission between repeaters. Many links operate in the 4 and 6 GHz region, but some links operate at 13 GHz n . Propagation is of course by means of the space wave and therefore limited to line of sight. Typical repeater spacing are close to 50 km, unless a city repeater is located on top of special tower, or a country one on a hill. Even then, much larger repeater spacing cannot be used because of the very high attenuation with distance.

11.12 SATELLITE COMMUNICATION

Long distance communication using conventional techniques like coaxial cable or microwave radio relay links involves a large number of repeaters.

Arthur (C) Clarke in 1945 proposed that worldwide coverage could be obtained by using three microwave repeaters placed in a Geostationary orbit at the height of about 36000 kms with a period of 24 hours figure.

Satellite communication provide a practical and economical means of long haul communication traffic in a country with a large geographical area.

It also enables communication service to those areas which are virtually INACCESSIBLE by other conventional forms of communication system due to natural physical barriers.

A geostationary satellite is launched above the equator 36,000 km high above the earth. Its period round the earth

coincides with that of the earth rotation. Therefore, the satellite looks as if it is stationary from the earth. *If three (3) communication satellites are launched equidistantly above the equator; it can serve almost all communication network round the world.* Therefore, to facilitate public international telecommunications, INTELSATS IV and V have been launched above the Atlantic, Pacific, and Indian Oceans. These networks cover almost all countries around the world.

1. *Stable and large capacity communication.*
2. *Costs of establishment and maintenance do not depend on communication distance.* The costs of submarine and over-the-horizon systems are proportional to the length, but those of the satellite system do not affect the communication distance. Therefore, the satellite system is ideal for long distance communications.
3. *Multiple access is possible:* Signals sent from an earth station can be received at several earth stations simultaneously. Therefore, it can transmit signals to many stations simultaneously, such as TV. Actually, increasing of submarine cable's capacity and distance between repeaters, can make submarine cables competitive to satellite communication specially when very large capacity is required but for small traffic size countries, satellite communication is unavailable for the independent communication services.

Advantages of Satellite Communications

1. Large Coverage
2. High Quality
3. High Reliability
4. High Capacity
5. Flexibility
6. Speed of Installation
7. Mobile, Short-Term or Emergency Communications
8. Satellite communication is ideally suited for point to multipoint transmission on broadcasting over large areas. Application of satellites for TV broadcasting, audio and video distribution and teleconferencing, facsimile, data and news dissemination is, therefore, increasing rapidly.
9. All types of common services are possible.

Satellite Communication Network

The two important elements of a satellite communication network are:

1. Space Segment
2. Ground Segment.

Uplinks and Down Link: Uplink is the radio path from ground segment, i.e., earth station to the Space segment, i.e., satellite, whereas Downlink is the radio path from space segment, i.e., satellite to the ground segment, i.e., earth station.

Frequency Bands

Choice of Frequency band for space communication depends upon:

1. Band-width required.
2. Noise consideration.

Propagation Factors

Technological developments with regard to component and device.

As the signal levels from the satellite are expected to be very low, any natural phenomenon to aid the reception of the incoming signals must be exploited. Between the frequencies of 2 GHz to 10 GHz, the level of the sky-noise reduces and this band of frequencies is known as the ‘*microwave window*’.

The most of the communication satellites as on today are using a frequency of **6 GHz for “Up link” and 4 GHz for “Down link”** transmission.

These frequencies are preferred because of:

- Less atmospheric absorption than higher frequency.
- Less noise both galactic and manmade.
- Less space loss compared to higher frequency.
- A well developed technology available at these frequencies.
- 6 GHz/4 GHz bands are shared with terrestrial services, creating interference problem.
- As equatorial orbit is filling with geostationary satellites, RF interference is increasing from one satellite system to another is increasing. *14/11 and 30/20 GHz systems for telecommunication and broadcasting satellite services are slowly coming being.*

Time Delay

The total earth–satellite–earth path length may be as much as 74,000 km thus giving a **one-way propagation delay of 250 ms**. The effect of this delay on telephone conversations, where a 500 ms gap can arise between one person asking a question and hearing the other person reply, has been widely investigated, and was found to be less of a problem than had been anticipated. With geostationary satellites, two-hop operation sometimes unavoidable and gives rise to a delay of over one second.

Figure of Merit (G/T)

The earth stations are classified on the basis of figure of merit of earth station which is defined by the parametre ‘*G*’ by ‘*T*’ (*G/T*). *G* is the receive gain of the earth station antenna and *T* is the equivalent noise at LNA input. This noise includes:

Antenna Noise

Equivalent noise of receive chain (LNA, down converter) referred to LNA input.

The total noise is expressed in terms of noise temperature (Kelvin). Thus, *G/T* of an earth station in dB/K is given by

$$G/T = G_R - 10 \log T \text{ in dB}$$

where *G* is the receive gain of earth station antenna and *T* is noise temperature of the receive chain. A high *G/T* implies that an earth station can receive very weak signal because antenna gain is high and noise is low. Note that an LNA is specified by its noise temperature, i.e., by noise its generates.

Noise Temperature

The amount of receiver noise present is defined as receiver noise temperature T_{eq}^o . The parametre T_{eq}^o is an effective equivalent temperature that an external noise source would have to produce the same amount of receiver noise. The equivalent temperature is written as

$$T_{eq}^o = T_b^o + (F-1) 290^o$$

where, T_b^o = back ground noise temperature accounting for contribution collected by antenna.

Multiple Access Techniques

Each transponder of a communication satellite with its bandwidth of 36 MHz can, in principle, be used as a repeater for an RF channel between two earth stations. But considering that:

- The number of earth stations to be interconnected is such larger than the number of transponders.
- The capacity of a transponder is much more than what is required between a pair of earth stations.
- The capacity of a transponder needs to be shared by several earth stations. It is a problem of multiplexing, to which conventional frequency division and time division methods or more specialised solutions can be applied. *The techniques employed for sharing a common transponder by multiple stations are called **multiple access techniques**.*

Multiple access can be feasible only if the input and output of the repeater are accessible to all the stations. A communication satellite meets this requirement because it operates in broadcast mode, i.e., output of a transponder is received by all the stations irrespective of their geographical locations.

Types of multiple access

The transponder bandwidth may be shared by multiple earth stations using one of the following techniques:

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)
- Space Division Multiple Access (SDMA).

In this handout, we shall describe FDMA and TDMA multiple access techniques and cover only the principle of CDMA.

Frequency Division Multiple Access (FDMA)

FDMA is the most frequently used technique because it is simplest to implement. It involves:

- Dividing the transponder bandwidth into smaller frequency bands and assigning them to different earth stations.
- Transmitting the carriers towards the satellite within the assigned frequency bands.
- Retransmitting the carriers from the satellite after frequency translation and amplification by a common transponder.
- Receiving in each earth station all the carriers which contain telephony channels meant for the earth station.

FM/FDM/FDMA

Usually a carrier transmitted from an earth station is frequency modulated with a FDM band of telephony channels. The FDM band may contain channels for multiple destinations. At each destination earth station, the received carrier is demodulated and from the FDM band the channels meant for the station are stripped. This scheme is called FM/FDM/FDMA in short.

A station must receive the carriers of all the stations it has links with; and to receive the carriers it must have separate rec Standard Carrier Sizes.

The bandwidth and the intensity (transmitted power) of the carrier transmitted by an earth station depends on the size of modulating FDM band.

Capacity Reduction in FDMA

A very important point to be noted is that as the number of accesses to a transponder is increased, the total channel capacity actually realized from the transponder is reduced. This is primarily due to non-linear characteristics of the transponder. When amplifying several carriers simultaneously, the transponder generates intermodulation noise. The noise can be reduced if the transponder is operated below its rated output. But each carrier is to be transmitted by the satellite at a minimum specified level so that it may be received properly by the earth station. Therefore, to reduce the net output of a transponder, it is necessary to reduce the number of carriers. *Operating a transponder at output less than its rated power is called “back off”*. 3 dB back off means the transponder is used at half of its rated power capacity.

Advantages of FDMA

- It utilizes proven technology.
- If the existing terrestrial trunks are analog and are already multiplexed on FDM basis, FDMA is the most suitable.

Disadvantages of FDMA

- The full capacity of a transponder is not effectively utilized due to back off. Utilization efficiency is reduced when number of the carriers is increased.
- Each earth station needs to be equipped with as many receive chains as the number of carriers.

- It is difficult to reconfigure the frequency and traffic plans. For example, even to change frequency of a carrier, the receive chains at all the earth stations need to be modified.

TDMA Time Division Multiple Access

TDMA buffers are required to temporarily store the information bits to assemble the burst. From each of the input bit stream fixed number of bits are taken and time multiplexed. Then the possible containing the address of burst originating station is added. The digital burst so formed modulates a carrier to generate the carrier burst.

The received signal from the satellite consists of series of bursts from all transmitting stations. All the bursts are sequentially demodulated as they arrive by a single demodulator. From each demodulated burst, the bits meant for the station are separated out.

Advantages of TDMA

- Since there is only one carrier, the problem of intermodulation noise is avoided. The transponder can work at its full capacity without any back off.
- There are no frequency guard bands. So the bandwidth of the transponder is fully utilized.
- There is a single receive chain with common demodulator for all the bursts. Reconfiguration of the network can be easily done just by changing the time allocations.
- As the number of accesses is increased, there are more bursts but the transponder utilization does not deteriorate as in FDMA.
- It is equally suitable for digital voice (PCM) and data transmission.

Disadvantages of TDMA

- The TDMA technology is costlier than FDMA.
- If the existing trunks are multiplexed on FDM basis, additional equipment for analog to digital conversion is required.

Code Division Multiple Access (CDMA)

In CDMA, the transponder bandwidth is used by all the stations simultaneously and using the same carrier frequency. Before transmission, each carrier is so “coded” that it has no correlation with other carriers. If uncorrelated signals are mixed they can always be separated if their codes are known. A PRBS (Pseudo Random Binary Sequence) is used to “code” the carrier. A different PRBS is used for each carrier so that after coding the carriers are uncorrelated. When such carriers are transmitted by the earth stations to a common transponder, the signal received from the satellite by each earth station consists of a frequency band of mixed but uncorrelated carriers. Using the same PRBS, the carriers are decoded and separated.

Space-Division Multiple Access (SDMA)

In this multiple-access technique, resource allocation is achieved by exploiting the spatial separation of the individual users. In particular, multibeam antennas are used to separate radio signals

by pointing them along different directions. Thus, different users are enabled to access the channel simultaneously on the same frequency or in the same time slot.

These multiple access techniques share a common feature; allocation the communication resource of channel through the use of disjointedness (or orthogonality in the loose sense) in time, frequency, or space.

Earth Station Subsystems

The earth station equipment consists of the following main subsystems:

- Multiplexing Equipment
- Transit Chain
- Power Amplifiers
- Antenna System
- Low Noise Amplifier
- Receive Chain.

Basic functions of these subsystems are summarized in the following sections.

Antenna System

The antenna system consists of the following components:

- Mechanical Subsystem
- Feed
- Automatic Tracking Subsystem.

Low Noise Amplifier (LNA)

To receive very weak signals from the satellite, the output of diplexer is connected to a low noise amplifier through a 6 GHz transmit reject filter. It is mounted at the output of the diplexer just behind the main antenna reflector. The low noise amplifier is in 1+1 redundant configuration. It has 500 MHz bandwidth and it is a common amplifier for all the carriers transmitted by the satellite.

The output of the LNA is applied to a RF divider, so that the received signals from the satellite may be distributed to different receive chains.

Receive Chain

The receive chain consists of the following units:

- Down Converter
- Demodulator
- Base Band Processing Unit.

Space Segment

Space Segment comprises satellite, launch vehicle which carries the satellite into its orbit and a telemetry and telecommand ground station which monitors and controls the satellite in orbit. Communication satellites could be either passive or active. A passive satellite could be natural, e.g. the moon or artificial e.g. the ECHO satellite. The ECHO satellite was launched in 1960 and consisted of a big metal-coated balloon used as a reflector of microwave signals. However, relay via passive satellites is not technically an advan-

tageous proposition due to very high path losses encountered and only active satellites are now in use. Satellites could be low orbiting or could be located in the geostationary orbit 36,000 kms. above the equator. Most of the communication satellites are located in the geostationary orbit due to the advantages of large coverage, 24 hour availability and simple tracking requirements for ground stations.

A Satellite Consists of Essentially Two Parts

1. Communication payload
2. Support subsystems.

Communication or mission payload for communication satellites comprises communication transponders and transmit/receive antennas. Major support subsystems include:

- Structure
- Attitude and orbit control systems
- Electrical power system
- Thermal control system
- Telemetry and Telecomm and system
- Propulsion.

Communication Payload

Antennas

Radiation pattern of an antenna is determined mainly by two considerations:

To provide maximum gain over the coverage area, and to have minimum radiation towards areas outside the coverage area for reducing interference.

Spacecraft antennas usually consist of parabolic reflectors of aluminum or fiber glass with honeycomb structure. Offset feeds are used to obtain required beam shaping for the coverage area.

Communication Transponder

Communication transponder receives the signals from ground station through spacecraft antenna. Signal from antenna is amplified in the common receiver, down converted to transmit frequency band and then separated in number of channels through an input multiplexer. Signals in each channel are amplified in a travelling wave tube amplifier (TWT) or a solid state amplifier (SSPA) and after amplification are combined through an output multiplexer to feed to the antenna for transmission towards the earth.

Complete redundancy is provided for subsystems whose failure could result in failure of all communication channels such as common receiver unit. For front end amplifier field effect transistors are used. Noise figure of the front amplifier determines the spacecraft noise temperature and G/T (figure of merit). Solid state devices are used for all stages except for the final output stage where travelling wave tube amplifier is used. Transistor amplifiers for output stage also have now been developed and are likely to be used increasingly in future. Local oscillator in the mixer is crystal controlled and generally operates at frequency of 2225 MHz in case of conversion of incoming 6 GHz signals to 4 GHz downlink frequency. Input and output multiplexers are made of invar or graphite epoxy. Amplitude and group delay equalizers are provided to compensate for input and output multiplexer char-

acteristics. Step attenuators are inserted prior to output amplifier for adjusting transponder gain settings by telecomm and signals in accordance with transmission plan requirements.

11.13 RADAR

Radar refers to “Radio Detection and Ranging”. It detects mobile objects or targets by sending electromagnetic waves and analysing the received echoes. It is the most effective method of guiding a pilot in regard to his location in space; it is also the most effective means of warning about the approach of an enemy plane for sinister purposes. During the Second World War, Radar was used as warning posts called DEW (Distant Early Warning).

Gradually Radar came in for other uses as follows:

Radar altimetres	Height of plane above ground
Radar detectors	Landmasses, buoys in ocean navigation, search for submarines.
Radar blind lander	Ground Control Interceptor aircraft
Radar for Guided	For piloting electro magnetically controlled
Missiles (G.M.R)	Missiles
Airborne Radar	For satellite surveillance
Police Radar	Directing and detecting speeding automobiles.

The use of radar is ever increasing, as technological advance covers more explorations, probes, etc.

Limitations

- 1. Radars cannot resolve in detail like the human eye, especially by poor visibility or darkness.
- 2. They do not recognize the colour of the target.

Improved Radar

A modified block diagram is shown in figure which has another important block called the duplexer.

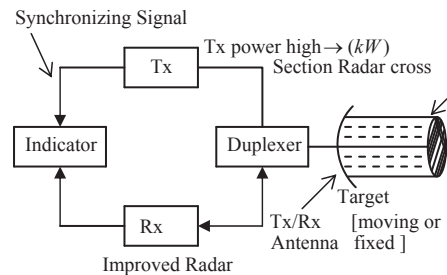


Fig. 11.14

The Functions of a Duplexer

- 1. To isolate the transmitter and receiver during transmission and reception.
- 2. To protect the receiver from high power transmitter.
- 3. To help use a signal transmitter/receiver antenna.

The received echo signal after it is processed by the receiver is displayed on the radar screen. It is very much possible to detect the height, speed and direction of travel of the target by space triangulation and by the time taken for the echo to come back after reflection from the target. The display screen can be similarly calibrated to indicate the target data.

The general requirement for any radar system are summarized as below:

- 1. The duplexer should be automatic in its operation.
- 2. The radar transmitter should remain silent during the echo period.
- 3. The transmitted pulse should be quite powerful to counter the attenuation during forward and return journeys.
- 4. The received echo pulse being weak, the receiver should be extremely sensitive and at the same time immune to noise (clutter) signals. It should have necessary amplification, signal processing circuitry and capability to display the target information on the radar screen.
- 5. The radar antenna should be highly directive and have a large gain so that it can radiate a strong signal and receive a weak pulse.
- 6. Pulse repetition frequency (prf) of the radar should be high compared to target scanning period where, prf is given by the relation $prf = \text{duty cycle} / \text{pulse width}$ i.e., A small duty cycle provides the necessary. Time required for the pulse to go to the target, get reflected and provide echo pulse for the radar receiver. Normally pulse lengths (widths) lie in the range of 0.1 to 10m sec. The average power depends on the transmitted power P_t and the duty cycle given by

$$P_{av} = P_t \times \text{duty cycle}$$
$$= P_t \times \text{pulse width} \times prf.$$

Classification

Radar system are broadly classified as two basic categories:

- 1. Pulse Radars
- 2. Continuous-wave (cw)/Doppler Radars.

Radar Frequencies in Microwave Range

It is obvious that radar should be in the Microwave range, refracting through all layers. Including Troposphere, Stratosphere and ionosphere because

- 1. Range should be long.
- 2. Resolution should be high.
- 3. High gain small size antenna structures should be possible.
- 4. Many radars are airborne and the EM waves generated by the radar should be penetrating.

Radar are in the 1 GHz–10 GHz band. Specific bands are allocated by CCIR for various specific radar usages and for different countries, to avoid channel interference. There are some radars up to 36 GHz.

Radar Bands as adopted by US Military

Band	Frequency (Wavelength) Range
<i>P</i>	0.22 GHz (133 cm)–0.3 GHz (77 cm)
<i>L</i>	0.39 GHz (77 cm)–1.55 GHz (19 cm)
<i>S</i>	1.55 GHz (19 cm)–3.9 GHz (7.7 cm)
<i>C</i>	3.9 GHz (7.7 cm)–6.3 GHz (4.8 cm)
<i>X</i>	6.3 GHz (4.8 cm)–10.9 GHz (2.7 cm)
<i>Ku, K, Ka</i>	10.9 GHz (2.7 cm)–36 GHz (8.3 cm)

Radar Bands

Band Name	Frequency Range, GHz	Maximum available peak power MW
UHF	0.3–1.0	
<i>L</i>	1.0–1.5	50
<i>S</i>	1.5–3.9	30.0
<i>C</i>	3.9–8.0	25.0
<i>X</i>	8.0–12.5	10.0
<i>Ku</i>	12.5–18.0	2.0
<i>K</i>	18.0–26.5	0.6
<i>Ka</i>	26.5–40.0	0.25
<i>V</i>	40.0–80.0	0.12
<i>N</i>	80.0–170.0	0.01
<i>A</i>	Above 170	

Note that the frequency ranges corresponding to the band names are not quite as widely accepted as the frequency spectrum band names.

This column shown the maximum available power per tube. Nothing prevents the use of several tubes in a transmitter to obtain a higher output power.

Radar Equation

Radar equation gives a method of evaluation of range of a radar in terms of controllable variables:

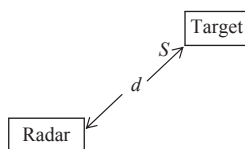


Fig. 11.15

Symbol

P_T	Peak power of transmitter section of radar
P_R	Peak echo (received) power at receiver section of radar
G_T	Gain of receiving antenna (in practice one and the same antenna is used, or $G_T = G_R$)
S	Area of target
D	Distance of target
A	Capture area of the receiver antenna.
A_o	Aperture area of receiver antenna and
K	$[A/A_o]$

$$\text{Power transmitted in space} = P_T G_T \quad (1)$$

This energy is spread around a sphere of radius

$$\text{Area of surface of the sphere} = 4\pi d^2$$

$$\text{Power density transmitted} = \frac{P_T G_T}{4\pi d^2} \quad (2)$$

$$\text{Power incident on Target} = \frac{P_T G_T}{4\pi d^2} \cdot S \quad (3)$$

Echo is the reflected/scattered energy. The entire reflected energy does not reach the radar.

The echo power per unit area of the wave front at the receive is

$$\text{Echo power} = \frac{P_T G_T}{4\pi d^2} \cdot S \times \frac{1}{4\pi d^2} = \frac{P_T G_T \cdot S}{(4\pi d^2)^2} \quad (4)$$

$$\text{Total received power} = \frac{P_T G_T \cdot S}{(4\pi d^2)^2} \cdot A$$

Effective aperture of an antenna is defined as the cross-sectional area, such that power absorbed by this area placed normal to the direction of propagation is equal to that actually absorbed by the antennal under matched condition.

$$A = (G_R) \times [\lambda^2/4\pi]$$

$$A = K A_o.$$

Dependence of Transmitted Power

$$R_R \propto P_T^{(1/4)}$$

Or to double the radar range, we have to increase transmitted power 16 times.

Dependence on Frequency

$$R_R \propto \frac{1}{\sqrt{\lambda}} \quad \text{or} \quad R_R \propto (\sqrt{f})$$

Increase of frequency will increase the range. But this requirement is in conflict with the dependence of beam width of the directional lobe of directional antenna power.

In a Parabolic antenna, beam width = $[\lambda/D]$ (D -diametre of parabola).

If λ decreases, the beam width becomes very narrow, which reduces the tracking range of the radar.

In a special type of radar called Search Radar, the sweep of the antenna will cover a certain portion of the sky. This will take a longer time, if the lobe width is very narrow.

Hence, we cannot increase the radar frequency far too much, because the radar will become ineffective even though the range may increase

- $G_T = G_R$ as same antenna is used for Both, transmitting and receiving.

$$R_R = \left(\frac{P_r \cdot S \cdot A^2}{4\pi \lambda^2 (P_R)_{\min}} \right)^{1/4}$$

$(P_R)_{\min}$ minimum received signal.

- Range depends on transmitted power frequency and target area.

$$R_R \propto (P_T)^{1/4}$$

$$R_R \propto f^{1/4}$$

$$R_R \propto \sqrt{A} = D$$

where Range is proportional to Diameter.

- Beam width = $[\lambda/D]$.

Blind Speed Defect

If the target has uniform velocity the successive sweeps will have 2π phase shifts and the target appears stationary and gives wrong radar indication.

$$V_b = \frac{n\lambda}{2} \times PRF$$

where, $n = 1, 2, 3 \dots$

Speed corresponding to this condition is called blind speed. But constant velocity is not possible for any target beyond a particular time and the echo will be netted in the third or fourth successive sweeps.

Applications

FMCW radar is mostly used as altimeter in aircrafts due to shorter ranges and lower power requirements as compared to pulsed radars smaller size for aircraft installations and smaller transmitter powers. Typical equipment developed for FMCW radar has a power less than 1 watt and operates at carrier frequency of 440 MHz with modulating frequency of 120 Hz and frequency deviation of either 2 or 20 MHz.

Radar Antenna Directivity

Radar Antenna has to be directive as they have to generate EM waves to score a hit on a target.

Scan Radars: Scanning can be in both vertical and horizontal planes.

Tracking: Motorized movement of the aerial about an axis is called Tracking.

Several methods of Tracking:

- Lobe switching or sequential lobbing → In this method, antenna beam is rapidly switched between two position, so that the strength of the echo from the target fluctuates at the switching unless the target is midway between the two direction when the echo strength is constant.
- **Conical Scanning:** The antenna is mounted off center and rotated about the axis of the antenna.

Advantage of using parabolic antenna:

- Large which increase with square of the microwave frequency.
- Its size reduces at higher frequencies.
- Effective Radiated power is several times the input power.
- Radiation is highly directional.
- Same Receiving and transmitting characteristic.

PRF (pulse repetition frequency)

They should be sufficient time for the pulse receiver should be receiver and during this period, the receiver should be on the Duplexer route.

Short Pulse are not Favoured in Radar Technique as

1. If the duration of pulse is small, the Bandwidth of the receiver should be large. If the Bandwidth is increased, the additive or thermal noise generated increased, decreases the range.
2. In order to overcome the above, if we increase power transmitted. But this will be costly.

$$\text{Unambiguous range: } d = \frac{C \cdot PRF}{2}$$

where, $d \rightarrow$ unambiguous Range

PRF $\rightarrow$ Pulse repetition frequency

$C \rightarrow$ Velocity of EM.

Blind Speed Defect

If the target has uniform velocity, the successive sweeps will have 2-phase shift and the target appears stationary and gives wrong indication. Speed corresponding to this condition is called Blind speed.

$$V_b = \frac{\eta \lambda^2}{2} \cdot PRF$$

where $\lambda =$ wavelength

$\eta = (1, 2, \dots)$ integers.

Staggered PRF

Sometimes we need to switch between two or more PRF to avoid Blind speed.

This is called staggered PRF. In this case we have option to choose different PRF.

QUESTION BANK

LEVEL 1

1. In the standing wave detector method for measuring a slightly mismatched load impedance, the distance from the load position to the nearest voltage minimum towards the generator is one-eighth the guide wavelength. The load is
 - (a) a capacitive impedance (b) an inductive impedance
 - (c) a pure capacitance (d) a pure inductance
2. Consider the following statements:
If the narrow dimension of a standard rectangular waveguide carrying the dominant mode is reduced, then the
 1. Wave impedance will increase
 2. Attenuation will increase
 3. Guide wavelength will decrease
 4. Power handling capability will decrease
 Which of these statements are correct?
 - (a) 1 and 2 (b) 2 and 4
 - (c) 3 and 4 (d) 1 and 3
3. At microwave frequencies, a varactor diode may NOT be useful
 - (a) For electronic tuning (b) For frequency multiplication
 - (c) as an oscillator (d) as a parametric
4. The correct sequence of the assembled parts in klystron amplifier from any end is
 - (a) Anode, catcher cavity, cathode and buncher cavity
 - (b) Cathode, buncher cavity, catcher cavity and anode
 - (c) Anode, buncher cavity, catcher cavity and cathode
 - (d) Cathode, catcher cavity, anode and buncher cavity
5. In parametric amplifiers used in microwave communication system, the gain is mainly restricted by
 - (a) Ambient temperature (b) Pump frequency
 - (c) Pump bandwidth (d) Pump energy
6. In a Gunn oscillator where the diode is operated in a tunable resonant circuit, most of the sample length of the Gunn device is maintained in the negative conductance state during most of the R.F. cycle for
 - (a) Delayed domain mode (b) Quenched domain mode
 - (c) LSA mode (d) Hybrid mode
7. Consider the following statements:
Cross field amplifier (CFA) is a microwave power amplifier which
 1. Is a case between the TWT and the magnetron in its operation
 2. Uses a magnetron structure to provide an interaction between crossed dc electric and magnetic field on one hand and RF fields on the other hand
 3. Uses interaction between electron beam and stationary RF fields

Select the correct answer using the codes given below

- (a) 1 and 2 (b) 1 and 3
 - (c) 3 alone (d) 2 and 3
8. Broad banding a microwave transistor RF amplifier is difficult because
 - (a) Of shunt capacitance loading effect
 - (b) Of series capacitance loading effect
 - (c) Changes in inductive loading affect terminating impedance
 - (d) Changes in output loading affect input impedance
 9. For using as a local oscillator for frequency measurements, the most suitable microwave source would be
 - (a) Travelling wave tube (b) Double cavity klystron
 - (c) Reflex klystron (d) Magnetron
 10. The correct sequence of subsystems of Klystron amplifier as they appear in the direction of flow of the electron below is
 - (a) Buncher cavity, Cathode, Collector, Catcher cavity
 - (b) Buncher cavity, Cathode, Catcher cavity, Collector
 - (c) Cathode, Buncher cavity, Catcher cavity, collector
 - (d) Cathode, Buncher cavity, Collector, Catcher cavity
 11. A slotted line is used for the measurement of VSWR. The slot is cut at the center because
 - (a) The field inside the waveguide will not be perturbed
 - (b) To get a good impedance matching
 - (c) Maximum field will be induced to the penetrating probe
 - (d) No field will be coupled to the probe
 12. The variation of resistance of an element with absorption of microwave power is the underlying principle of operation of a/an
 - (a) Attenuator (b) Wave filter
 - (c) Phase shifter (d) Bolometre
 13. In a reflex klystron. The velocity modulation
 - (a) Occurs near the reflector
 - (b) Occurs in the resonator gap
 - (c) Occurs near the accelerating grid
 - (d) Does not occur at all
 14. As an ideal local oscillator for microwave frequency measurements, the most suitable microwave source is a
 - (a) Multicavity magnetron (b) Reflex klystron
 - (c) Double cavity klystron (d) Traveling wave tube
 15. Which one of the following can be used for amplification of microwave signals?
 - (a) Gunn diode (b) Strapped magnetron
 - (c) Reflex klystron (d) Double cavity klystron
 16. If the height of the waveguide is halved, its cut-off wavelength will
 - (a) Be halved
 - (b) Be doubled

11.18 ■ Microwave Engineering

- (c) Remain unchanged
(d) Be one fourth of the previous value
17. A cavity wavemeter is connected parallel to waveguide transmission line which terminates in a resistive load. The microwave power reaching the load – end is monitored by a power metre. As the cavity wavemeter is tuned to the resonant frequency of the input signal through the waveguide assembly, the power indicated by the power metre will show
(a) A sudden dip (b) A sudden rise
(c) Rapid fluctuations (d) A steady level
18. A two-port non-reciprocal device which produces a minimum attenuation to em wave propagation in one direction and a very high attenuation in opposite direction is generally known as
(a) Phase shifter (b) Isolator
(c) Polarizer (d) Circulator
19. A metal probe inserted into a rectangular waveguide through the broader wall of the guide will provide property across the guide. This property is a
(a) Shunt (b) Reactance
(c) Reverberation (d) Resonance
20. Consider the following statements:
A travelling wave tube is
1. Broad-band amplifier
2. Linear beam amplifier
3. Crossed field amplifier
4. Solid-state amplifier
Which of the statements given above are correct?
(a) 1 and 2 (b) 2 and 4
(c) 2 and 3 (d) 1, 3 and 4
21. Consider the following pairs:
1. Travelling wave tube : Linear electron beam
2. Cavity Magnetron : Strapping
3. Amplitron : CFA
Which of the pairs given above are correctly matched?
(a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3
22. In parametric amplifiers used in microwave communication systems, the pump energy mainly restricts which one of the following?
(a) Bandwidth (b) Gain
(c) Noise level (d) Operating frequency
23. Which one of the following statements is correct?
Microwave link repeaters are typically 50 km apart
(a) Because of atmospheric attenuation
(b) Because of output tube power limitations
(c) Because of earth's curvature
(d) To ensure that the applied *d.c.* voltage is not excessive
24. Why is an attenuator used in a TWT?
(a) To help bunching (b) To prevent oscillations
(c) To prevent saturation (d) To increase gain
25. In the Gunn diode, out of its various modes of operation, one mode is independent of domain transit time and hence can be used at high frequency and for very high output powers. Which is this mode?
(a) transit time mode
(b) Quenched domain mode
(c) Delay domain mode
(d) Limited space charge accumulation mode
26. Silicon and Germanium are not suitable for fabrication of laser diodes because
(a) Their absorption coefficients are very high
(b) Their emission coefficients are very low
(c) They have direct band gap
(d) They have indirect band gap
27. Two-valley model of the *Ridley-Watkins Hilsum theory* is best suited to explain the working of which one of the following?
(a) Quartz crystal oscillator
(b) Gunn Diode oscillator
(c) Klystron oscillator
(d) *R-C* oscillator
28. The working of a traveling wave tube is based on the interaction between
(a) Moving electrons and the transverse component of a progressive em wave
(b) Moving electrons and the axial component of a progressive em wave
(c) Moving electrons and the transverse component of a rotating magnetic field
(d) Moving electrons and the axial component of a steady magnetic field
29. Which of the following are microwave sources?
(a) Klystron (b) Magnetron
(c) IMPATT (d) TWT
30. To prevent oscillations in the TWT which one of the following is resorted to?
(a) Bunching defocusing mechanism is used
(b) Attenuator is used
(c) External magnetic field is provided
(d) Helix is used
31. Which of the following microwave components has got the combined characteristics of dielectric, ohmic and radiation losses?
(a) Waveguide
(b) Microstrip line
(c) Co-axial line
(d) Parallel twin line
32. By measuring the VSWR values in the main and ancillary waveguides of a directional coupler, we can determine its
(a) Phase co-relation and efficiency
(b) Frequency shift and phase variations
(c) Attenuation and radiation efficiency
(d) Directivity and coupling factor

33. In terrestrial microwave links, the number of 'fades' per unit time increases as
- Both the transmission frequency and the distance between the antennas are increased
 - The transmission frequency is increased but the distance between the antennas is decreased
 - The transmission frequency is decreased but the distance between the antennas is increased
 - Both the transmission frequency and the distance between the antennas are decreased
34. In parametric amplifiers used in microwave communication systems, the 'pump energy' is the deciding factor for which one of the following?
- Frequency stability
 - Maximum output
 - Amplification factor
 - Thermal noise level
35. By using a travelling wave structure in a maser, we may
- Increase the bandwidth of operation
 - Increase the power output
 - Stabilize the frequency of operation
 - Minimize the noise level and distortion
36. In general, attenuation per unit length in a coaxial cable
- increases with frequency
 - decreases with frequency
 - remains constant with frequency
 - depends upon the type of coaxial cable. It can either increase or decrease
37. Which of the following instruments may be used to measure the optical activity of compounds?
- Infrared spectrometre
 - Atomic absorption spectrometre
 - Polarimetre
 - Flouroscope
38. Helix is used in TWT
- Reduces the band width
 - Acts as a coaxial transmission line
 - Reduce inductance/unit length
 - Increase phase velocity
39. A Gunn diode can replace reflex klystron in
- Signal generators
 - Frequency modulated power oscillators
 - Parametric amplifier pumps
- 1 and 2
 - 2 and 3
 - 1 and 3
 - 1, 2 and 3
40. For microwave propagation through micro strip lines, there will be
- Radiation, eddy current and dielectric losses
 - Dielectric, ohmic and hysteresis losses
 - Dielectric, ohmic and radiation losses
 - Ohmic, hysteresis and eddy current losses
41. A cavity wave metre measures microwave frequencies because, the cavity
- Offers high impedance to microwaves
 - Has more volume for microwaves to interact
 - Will have a resonance with one frequency of the microwaves signal
 - Offers a resistive load
42. In Gun diodes, electrons are transferred from
- High to low mobility energy bands
 - Low to high mobility energy bands
 - Valley to domain formation
 - Domain to valley formation
43. Two linearly polarized plane waves *A* and *B* traveling in free space in the positive *X* direction meet at a point. The wave *A* is polarized in the *Y* direction and the wave *B* is polarized in the *Z* direction. The resulting wave is linearly polarized. Therefore, *A* and *B*
- Must have equal amplitudes and must also be in time phase with each other
 - Must have equal amplitudes but need not be in time phase
 - May have different amplitudes but must be in phase with each other in time
 - May have different amplitude and may also differ in time phase
44. The dominant mode in a wave guide is characterized by
- Longest cutoff wavelength
 - Shortest cutoff wavelength
 - Infinite attenuation
 - Zero attenuation
45. When a particular mode is excited in a wave guide there appears an extra electric component in the direction of propagation. The resulting mode is
- Longitudinal electric
 - Transverse electromagnetic
 - Transverse magnetic
 - Transverse electric
46. Microwave link repeaters are typically 50 km apart in TV transmission because
- Of atmospheric attenuation
 - Of output power tube limitations
 - Microwave transmission is through surface wave which attenuates faster
 - Of earth's curvature
47. A microwave junction is supposed to be matched at all ports if in the *S* matrix
- All the diagonal elements are zero
 - All the diagonal elements are equal but not zero
 - All the diagonal elements are complex
 - Is Hermitian
48. Wave-guides are pressurized above normal atmospheric pressure for
- Increasing their power handling capacity
 - Improving the conductivity of their walls
 - Preventing higher order modes from propagating
 - Varying the wave impedance

49. A duplexer is used to
 - (a) Couple two antennas to a transmitter without interference
 - (b) Isolate the antenna from the local oscillator
 - (c) Prevent interference between two antennas connected to a receiver
 - (d) Use same antenna for reception or transmission without interference
50. The positions of the probe for half power points in the slotted line of a microwave bench are interpreted to measure
 - (a) guide wavelength
 - (b) load impedance
 - (c) source frequency
 - (d) high SWR
51. In laboratory experiments the output from reflex Klystrons are modulated by square waves because
 - (a) It is easy to generate a square wave
 - (b) Crystal diode operates in the square law region of the I - V characteristics
 - (c) It prevents frequency modulation
 - (d) Detector circuit is less complicated
52. The guide wavelength is measured by short-circuiting a waveguide and shifting the tunable probe along the slotted line to locate the voltage minima. If the shorting plate is replaced by a matched load, then
 - (a) It would improve the accuracy of the measurement
 - (b) The guide wavelength cannot be measured
 - (c) It will give less accurate result, as no reflected wave is present
 - (d) It will change the value of the guide wavelength
53. Which one of the following is the correct sequence of frequency bands in order of increasing available peak power?
 - (a) C-band, X-band, L-band, S-band
 - (b) X-band, C-band, S-band, L-band
 - (c) X-band, S-band, C-band, L-band
 - (d) S-band, X-band, C-band, L-band
54. In π -mode operation of magnetron, the spokes due to phase focusing effect rotate at an angular velocity corresponding to
 - (a) one pole/cycle
 - (b) two poles/cycle
 - (c) four pole/cycle
 - (d) six poles/cycle
55. Consider the following statements relating to problem of mounting the bolometer in a waveguide for microwave power measurement
 1. The first requirement in the mounting is that the mount and bolometer match the impedance of the waveguide and this can completely be solved by incorporating tuning elements
 2. The operating resistance of the bolometer, determined by the point of operation may be such as one of the variable in impedance-matching and is chosen to be about equal to the characteristic impedance of the waveguide
 3. Mechanically it is very difficult to ensure that bolometer is subject to the microwave power and power and at the same time arranged so that it can be connected in low frequency bridge circuit
 4. A stub and short-circuited section behind the bolometer are introduced for canceling reflection at frequency different from the center frequency and thus to increase the bandwidth of the mount

Of these statements

- (a) 1, 2 and 3 are correct
 - (b) 1, 3 and 4 are correct
 - (c) 2, 3 and 4 are correct
 - (d) 1, 2 and 4 are correct
56. A disadvantage of micro-strips with respect to strip-line circuits is that the former
 - (a) Do not lend themselves to printed-circuit techniques
 - (b) Are more likely to radiate
 - (c) Are bulkier
 - (d) Are more expensive and complex to manufacture
57. The front end of an amplifier chain in a microwave communication system is kept immersed in liquid nitrogen, to
 - (a) Dissipate heat generated by amplifier
 - (b) Expand its frequency response
 - (c) Improve its noise figure
 - (d) Reduce the distortion by the amplifier
58. Which one of the following statements is not true for strip line when compared to a waveguide?
 - (a) It can be directly connected to semiconductor microwave devices
 - (b) It is much smaller in size
 - (c) It has a smaller band width
 - (d) Losses are less
59. In cavity magnetron strapping is used to
 - (a) Prevent mode jumping
 - (b) Prevent cathode back heating
 - (c) Ensure bunching
 - (d) Improve the phase focusing effect
60. Which one of the following statements regarding a microwave link is incorrect?
 - (a) Uses line of sight propagation
 - (b) Uses reflection type antennas
 - (c) Can operate from 1 MHz onwards
 - (d) Uses repeaters to increase the range
61. Transmission of signals in a terrestrial microwave system is achieved through
 - (a) Reflection from the ionosphere
 - (b) Line of sight mode
 - (c) Reflection from the ground
 - (d) Diffraction from the stratosphere
62. Which one of the following is a transferred electron device?
 - (a) BARITT diode
 - (b) IMPATT diode
 - (c) Gunn diode
 - (d) Step recovery diode
63. The slow-wave structure of a TWT is provided with an attenuator. Which one of the following is the function of such an attenuator?
 - (a) It prevents the RF power from reaching the output of the device when the beam is switched on
 - (b) It prevents oscillations in the device
 - (c) It reduces the noise level of the device
 - (d) It is used to broadband the device
64. A waveguide section in a microwave circuit will act as a
 - (a) low pass filter
 - (b) band pass filter
 - (c) high-pass filter
 - (d) band-stop filter

65. Consider the following statements associated with micro strip patch antenna:
1. The micro-strip patch behaves more like a leaky cavity rather than like a radiator and thus is not a highly efficient antenna
 2. They are broadband antenna and are well suited for mm-waves
 3. They can be adapted for radiation of circularly polarized waves
- Of these statements:
- (a) 1, 2 and 3 are correct
 - (b) 1 and 2 are correct
 - (c) 2 and 3 are correct
 - (d) 1 and 3 are correct
66. "Double-the-minimum" method is relevant to the measurement of
- (a) low attenuation coefficient
 - (b) high attenuation coefficient
 - (c) high VSWR
 - (d) low VSWR
67. A slot line is etched on the ground plane of a microstrip. Coupling between the slot line and the microstrip, on the two sides of the same substrate, takes place through which one of the following mechanisms?
- (a) The coupling is magnetic and is the minimum when they are at high angles
 - (b) The coupling is electric and is the maximum when they are parallel
 - (c) The coupling is magnetic and is the maximum when they are at the right angles
 - (d) The coupling is electric and is the minimum when they are at right angles
68. In a hollow rectangular waveguide, the phase velocity
- (a) Increases with increasing frequency
 - (b) Decreases with increasing frequency
 - (c) Is independent of frequency
 - (d) Will vary with frequency depending upon the frequency range
69. Evanescent mode attenuation in waveguide depends upon the
- (a) Conductivity of the dielectric filling the waveguide
 - (b) Operating frequency
 - (c) Conductivity of the guide walls
 - (d) Standing waves in the guide
70. Which one of the following is caused by reflection from stratified atmosphere or from the surface or land condition along the path?
- (a) Multi-path fading
 - (b) Selective fading
 - (c) Duo fading
 - (d) Reflection fading
71. Which one of the following can be used for amplification of microwave energy?
- (a) Traveling wave tube
 - (b) Magnetron
 - (c) Reflex klystron
 - (d) Gunn diode
72. Consider the following statements: In a magic tee
1. The collinear arms are isolated from each other
 2. One of the collinear arms is isolated from the E-arm
 3. One of the collinear arms is isolated from the H-arm
4. E-arm and H-arm are isolated from each other
- Of these statements
- (a) 1 and 2 are correct
 - (b) 1 and 3 are correct
 - (c) 1 and 4 are correct
 - (d) 2 and 3 are correct
73. In microwave power measurements using bolometer, the principle of working is variation of
- (a) Inductance with absorption of power
 - (b) Resistance with absorption of power
 - (c) Capacitance with absorption of power
 - (d) Cavity dimensions with heat generated by the power
74. For the dominant mode, in a rectangular waveguide with breadth 10 cm, the guide wavelength for a signal of 2.5 GHz will be
- (a) 12 cm
 - (b) 15 cm
 - (c) 18 cm
 - (d) 20 cm
75. Which one of the following types of hollow cavity resonators of the same surface area would have the highest Q factor?
- (a) Spherical cavity made of copper
 - (b) Spherical cavity made of silver
 - (c) Cylindrical cavity made of copper
 - (d) Cylindrical cavity made of silver
76. When the phase velocity of an electromagnetic wave depends on frequency in any medium, the phenomenon is called
- (a) scattering
 - (b) polarization
 - (c) absorption
 - (d) dispersion
77. A cavity is a
- (a) Low pass filter
 - (b) High pass filter
 - (c) Band pass filter
 - (d) Band stop filter
78. The amounts of time-average energies stored in electric and magnetic field for p -th mode of a cavity resonator will be
- (a) Always equal
 - (b) Equal provided Q -factor is very high
 - (c) Equal in the spherical cavities
 - (d) Equal in the case of fundamental mode of oscillation
79. A cavity resonator can be represented by
- (a) an LC circuit
 - (b) an LCR circuit
 - (c) a loss inductor
 - (d) a loss capacitor
80. For a hollow waveguide, the axial current must necessarily be
- (a) A combination of conduction and displacement currents
 - (b) Conduction current only
 - (c) Time-varying conduction current and displacement current
 - (d) Displacement current only
81. The phenomenon of microwave signals following the curvature of earth is known as
- (a) Faraday effect
 - (b) Ducting
 - (c) Wave tilt
 - (d) Troposcatter
82. For a wave propagating in an air-filled rectangular waveguide
- (a) Guided wavelength is never less than the free space wavelength
 - (b) Wave impedance is never less than the free space impedance
 - (c) TEM mode is possible if the dimensions of the waveguide

are properly chosen

(d) Propagation constant is always a real quantity

83. Consider the following statements with reference to Brewster angle

1. For oblique incidence at a boundary, there is no reflected wave when the incident wave is vertically polarized
2. Brewster angle can occur only at the boundary of a perfect conductor
3. For a horizontally polarized wave, there is no Brewster angle
4. When the incident wave is not fully vertically polarized, there will be a reflected component which is horizontally polarized

Which of these statements are correct?

- (a) 1, 2 and 3 (b) 2, 3 and 4
(c) 3, 4 and 1 (d) 4, 1 and 2

84. When a particular mode is excited in a wave-guide, there appears an extra electric component in the direction of propagation. The resulting mode is

- (a) Transverse-electric (b) Transverse-magnetic
(c) Longitudinal (d) Transverse-electromagnetic

85. At microwave frequencies, a varactor diode may NOT be useful

- (a) For electronic tuning (b) For frequency multiplication
(c) As an oscillator (d) As a parametric

LEVEL 2

1. For a micro-strip with a substrate if dielectric constant ϵ , the value of effective dielectric E_c will be such that

- (a) $\frac{\epsilon}{2} < \epsilon_c < \epsilon$ (b) $\frac{(\epsilon+1)}{2} < \epsilon_c < \epsilon$
(c) $1 < \epsilon_c < \frac{(\epsilon+1)}{2}$ (d) $\frac{(\epsilon-1)}{2} < \epsilon_c < \frac{(\epsilon+1)}{2}$

2. If the peak power of pulsed microwave system is 10^4 W and the average power is 800 W, then the duty cycle will be

- (a) 80% (b) 8%
(c) 0.8% (d) 0.08%

3. A quarter-wave transformer matching a 75 W source with a 300W load should have a characteristic impedance

- (a) 50W (b) 100W
(c) 150W (d) 200W

4. For a Gunn diode oscillator, the drift velocity of the electron is 10^7 cm/s and the active region length is 10×10^{-4} cm. The natural frequency of oscillation would be

- (a) 1 MHz (b) 10 MHz
(c) 1 GHz (d) 10 GHz

5. A cylindrical cavity resonator has diameter of 24 mm and length 20 mm. The dominant mode and the lowest frequency band are operated as

- (a) TE_{111} and X-band (b) TM_{111} and C band
(c) TM_{011} and Ku-band (d) TM_{010} and X-band

6. A rectangular wave guide measure 3×4.5 cm internally and has a 9 GHz signal propagated in it. The cut off wavelength for TE_{10} mode is

- (a) 5 cm (b) 10 cm
(c) 15 cm (d) 9 cm

7. Which of the following is not possible in a circular wave guide?

- (a) TE_{10} (b) TE_{01}
(c) TE_{11} (d) TE_{12}

8. An IMPATT diode has a drift length of 4mm. The drift velocity of Si is 10^5 m/s. The operating frequency of the IMPATT diode is

- (a) 25 GHz (b) 20 GHz
(c) 12.5 GHz (d) 125 MHz

9. In a microwave measurement set-up, the power reaching to the load is found to be 50 mW. If a 3 dB coupler is placed before the load, the power to the load will be

- (a) 50 mW (b) 25 mW
(c) 12.5 mW (d) 6.25 mW

10. For a Gunn diode, the drift velocity of electron through active drift region is 10^7 cm/s and the active region is 10×10^{-4} cm. The critical voltage of the diode (Critical field = 3.2 k V/cm) is

- (a) 0.032 V (b) 0.32 V
(c) 3.2 V (d) 32 V

11. The maximum theoretical out put circuit efficiency of a double resonator klystron amplifier is

- (a) 25% (b) 50%
(c) 58% (d) 85%

12. In a rectangular wave guide with broader dimension a and narrow dimension b, the dominant mode of microwave propagation would be

- (a) TE_{10} (b) TM_{10}
(c) TE_{01} (d) TM_{01}

13. Two one-port cavity resonators having coupling coefficients K_1 and K_2 and identical resonant frequency ω_0 produce identical VSWR when used as terminating loads of a waveguide. Which one of the following relations is satisfied by K_1 and K_2 ?

- (a) $K_1 - K_2 = 0$ (b) $K_1 K_2 = 0$
(c) $K_1 K_2 = \frac{1}{2}$ (d) $K_1 + K_2 = 1$

14. In a GaAs gun diode the drift velocity is 10^7 cm/s and active region length is 10^{-3} cm. What is the natural frequency of oscillation?

- (a) 8 GHz (b) 9 GHz
(c) 10 GHz (d) 11 GHz

15. A rectangular waveguide operating in the dominant mode is gradually deformed into circular cross-section in the direction of propagation. What is the mode at the output?

- (a) TM_{11} (b) TE_{11}
(c) TE_{01} (d) TM_{01}

16. A 4-port microwave passive device has scattering matrix of the form

$$\begin{bmatrix} o & p & o & jq \\ p & o & jq & o \\ o & jq & o & p \\ jq & o & p & o \end{bmatrix}$$

Which one of the following statements is correct?

The device is a

- (a) Hybrid Tee (b) Hybrid ring
(c) H-port circulator (d) Directional coupler
17. N represents the number of electron transit cycles in the drift space of a two cavity klystron amplifier. What is the phase difference between the input signal voltage and the output current of the amplifier?
- (a) $(\pi/2 - 2\pi N)$ (b) $(\pi/2 + 2\pi N)$
(c) $(\pi - 2\pi N)$ (d) $(\pi + 2\pi N)$
18. A four port ideal directional coupler with infinite directivity is characterized by a S -matrix given as

(a)
$$\begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & S_{34} \\ S_{41} & S_{42} & S_{43} & 0 \end{bmatrix}$$

(b)
$$\begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

(c)
$$\begin{bmatrix} 0 & 0 & S_{13} & S_{14} \\ 0 & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & 0 \\ S_{41} & S_{42} & 0 & 0 \end{bmatrix}$$

(d)
$$\begin{bmatrix} S_{11} & S_{12} & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 \\ 0 & 0 & S_{33} & S_{34} \\ 0 & 0 & S_{43} & S_{44} \end{bmatrix}$$

19. Which one the following expresses the phase velocity in microstrip lines?
- (a) C/E_e (b) $c/\sqrt{E_e}$
(c) $C.E_e$ (d) $\sqrt{E_e}.C$
- C = Velocity of light in free space
 e_e = Effective dielectric constant

20. What are the characteristic impedance and the phase velocity on radio frequency lines?
- (a) $Z = \sqrt{L/C} \Omega$ and $v = \sqrt{L/C}$ m/s
(b) $Z = R + (1/\sqrt{LC}) \Omega$ and $V = 1/(\sqrt{LC})$ m/s
(c) $Z = (\sqrt{L/C}) \Omega$ and $v = (1/\sqrt{LC})$ m/s
(d) $Z = R + (\sqrt{L/C}) \Omega$ and $v = (1/\sqrt{LC})$ m/s

21. A uniform plane electromagnetic wave is normally incident upon a thick magnetic material such that its complex permittivity is equal to its complex permeability i.e., $\mu^* = \epsilon^*$. Which one of the following is the correct statement?

- (a) There will not be any reflection from the material
(b) A part of the wave will be reflected such that reflection coefficient would be 0.5
(c) Reflection coefficient would be close to 1
(d) Transmission coefficient would be 0.9

22. We have the following six sets of electro-magnetic waves with the frequency ranges as follows:

- 30–300 kHz
10–30 kHz
3–30 MHz
300–3000 kHz
30–300 MHz
> 300 MHz

These are designated in the following orders

- (a) VLF, LF, MF, VHF and UHF
(b) LF, VLF, MF, HF, VHF and UHF
(c) LF, VLF, HF, MF, VHF and UHF
(d) VHF, VLF, HF, MF, LF and UHF

23. The dominant mode in a rectangular wave-guide is

- (a) TE_{01} (b) TM_{01}
(c) TE_{10} (d) TM_{11}

24. For a directional coupler, the power is in the ratio of 100 : 1

- (a) 40 db (b) 30 db
(c) 20 db (d) 10 db

25. In a rectangular cavity resonator having a = width, b = height and d = length for $a > b < d$, the dominant mode is

- (a) TE_{101} (b) TM_{101}
(c) TE_{110} (d) TM_{110}

26. The transmission loss for a 3 GHz microwave system over a certain distance is 130 dB. If the frequency is now doubled, then the transmission loss will be

- (a) 136 dB (b) 133 dB
(c) 127 dB (d) 139 dB

27. The frequency of resonance of water vapour in the atmosphere is

- (a) 10.225 GHz (b) 12.850 GHz
(c) 17.500 GHz (d) 60.000 GHz

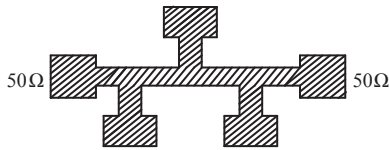
28. Which one of the following modes has the characteristic of attenuation becoming less as the frequency is increased and is attractive at microwave frequency of circular cylindrical waveguides?

- (a) TE_1 mode (b) TM_{01} mode
(c) TE_{01} mode (d) Higher order mode

29. A signal propagated in a wave guide has full wave of the electric intensity change between the two walls and no component of the electric field in the direction of propagation. The mode is

- (a) TE_{11} (b) TE_{10}
(c) TM_{22} (d) TE_{20}

30. For a cavity resonator with Q_e = unloaded Q and ρ standing wave ratio, Q_e the loaded Q is given by
- (a) $Q_e = \rho Q_o$ (b) $Q_e = \frac{\rho+1}{\rho} Q_o$
- (c) $Q_e = \frac{\rho}{1+\rho} Q_o$ (d) $Q_e = \frac{1}{\rho} Q_o$
31. The full-duplex round-trip delay through a synchronous satellite is approximately
- (a) 300 msec (b) 550 msec
- (c) 600 msec (d) 800 msec
32. The following figure shown the conductor pattern of a micro strip-line version of a microwave filter. This represents a



- (a) band pass filter (b) high pass filter
- (c) low pass filter (d) channel dropping filter
33. What are the directions of E and H in TEM mode transmission lines with respect to the direction of propagation?
- (a) Both $\vec{E}$ and $\vec{H}$ are entirely transverse to the direction of propagation
- (b) $\vec{E}$ is entirely transverse to and H has a component in the direction of propagation
- (c) $\vec{H}$ is entirely transverse to and $\vec{E}$ has a component in the direction of propagation
- (d) Both $\vec{E}$ and $\vec{H}$ have components in the direction of propagation
34. In a rectangular wave-guide there is one half-wave variation of electric field across the narrow dimension and two half-wave variations of electric field across the wider dimension. What is the dominant mode?
- (a) TM_{12} (b) TE_{12}
- (c) TE_{21} (d) TM_{21}
35. Which one of the following statements is true for e.m. wave propagation through a rectangular wave-guide of cross section $2a \times a$? Critical wavelength for TE_{10} mode is
- (a) The same as the for TE_{21} mode
- (b) Half that for TM_{01} mode
- (c) The same as that for TM_{01} mode
- (d) Double that for TE_{01} mode
36. A circular air filled wave-guide of radius 5 cm is operated in the H_{01} mode. The wave-guide is then completely filled with a dielectric of relative permittivity 2.25 and relative permeability. The cut-off wavelength for the H_{01} mode is 0.082 m when the wave-guide is air-filled. When the wave guide is filled with the dielectric, the cut-off frequency will become nearly
- (a) 1.60 GHz (b) 2.44 GHz
- (c) 3.66 GHz (d) 4.00 GHz

37. The critical angle in degrees, for an electromagnetic wave passing from quartz ($\mu = \mu_0, \epsilon = 4 \epsilon_0$) into air is
- (a) 15 (b) 30
- (c) 45 (d) 90
38. The lowest TM mode in a rectangular wave guide of cross-section $a \times b$ with $a > b$ will be
- (a) TM_{01} (b) TE_{10}
- (c) TM_{12} (d) TE_{11}
39. An electromagnetic plane wave propagates in a dielectric medium characterized by, $\epsilon_r = 4$ and $\mu = 1$. The phase velocity of the wave will be
- (a) 0.75×10^8 m/s (b) 1.5×10^8 m/s
- (c) 3×10^8 m/s (d) 6×10^8 m/s
40. The intrinsic impedance of free space is known to be 377Ω . The intrinsic impedance of a medium with relative permittivity of 4 and 1 respectively will be
- (a) 75Ω (b) 94Ω
- (c) 188Ω (d) 377Ω
41. If u_g is the velocity of propagation in a guide filled with a medium having the same permittivity as that of the unbounded medium, then u , u_p and u_g are related as
- (a) $u_p u = u^2$ (b) $u_g u = u_p^2$
- (c) $u_p u_g = u_p^2$ (d) $(u - u_p)(u - u_g) = u^2$
42. In the case of a cubic cavity resonator, the degenerate modes would include
- (a) TM_{111} , TE_{011} and TE_{101} (b) TM_{110} , TE_{011} and TE_{111}
- (c) TM_{110} , TE_{012} and TE_{102} (d) TM_{110} , TE_{011} and TE_{101}
43. For reliable "beyond-the-horizon" microwave communication, without using repeaters, the frequency of choice would be
- (a) 1 MHz (b) 30 MHz
- (c) 200002 MHz (d) 30,000 MHz
44. The transit time (in cycles) for the electrons in the repeller-space of a reflex klystron oscillator for sustaining oscillations (n is any integer including zero)
- (a) $2(\pi - 1)$ (b) $2n - 1$
- (c) $[n + \{1/2\}]$ (d) $[n + \{3/4\}]$
45. Guide wavelength (λ_g), cut-off wavelength (λ_c) and free-space wavelength (λ_o) of a wave-guide are related as
- (a) $\frac{1}{\lambda_g^2} = \frac{1}{\lambda_o^2} - \frac{1}{\lambda_c^2}$ (b) $\frac{1}{\lambda_o^2} = \frac{1}{\lambda_g^2} - \frac{1}{\lambda_c^2}$
- (c) $\frac{1}{\lambda_c^2} = \frac{1}{\lambda_o^2} - \frac{1}{\lambda_g^2}$ (d) $\frac{1}{\lambda_g^2} = \frac{1}{\lambda_o^2} - \frac{1}{\lambda_c^2}$
46. A cylindrical cavity resonator has a diameter of 16 mm. What is the dominant resonant mode when the cavity length is (i) 20 mm and (ii) 15 mm?
- (a) TE_{111} TM_{111}
- (b) TM_{010} TE_{111}
- (c) TE_{111} TM_{010}
- (d) TM_{111} TE_{011}

47. In a circular wave-guide with radius ' r ', the dominant mode is
 (a) TM_{01} (b) TE_{01}
 (c) TM_{11} (d) TE_{11}
48. For an open-ended rectangular wave-guide antenna of size $0.9'' \times 0.4''$ excited in the TE_{10} (dominant)-mode at $L = 3$ cm, the gain is nearly
 (a) 1.5 (b) 2.5
 (c) 26.5 (d) 36.5
49. A calorimetric measurement for average power of a signal gave a value of 400 W. The value was interpreted or peak power as 0.5 mW. Then the duty cycle of the signal is
 (a) 0.08 per cent (b) 80 per cent
 (c) 40 per cent (d) 80 per cent
50. A micro-strip line on alumina substrate ($\epsilon_r = 9$) has a zero thickness strip of width, $W = 3$ mm. Substrate thickness $h = 0.5$ mm. Assuming TEM wave propagation and negligible fringing field, the characteristic impedance of the line will be approximately
 (a) 10Ω (b) 21Ω
 (c) 26Ω (d) 50Ω
51. As the operating frequency is increased, micro-strip circuits suffer from undesirable effect which set an upper limit on the frequency. One of these is the lowest order TE transverse resonance that occurs for wide strips that form parallel plate wave-guide with the ground plane. In view of this, consider a micro-strip line with strip width $W = 2.1$ mm, substrate permittivity of 9, substrate thickness $h = 1.0$ mm and $d = 0.2 h$, the additional length that accounts for the fringing capacitance. The lowest order TE transverse resonance frequency will be
 (a) 10 GHz (b) 20 GHz
 (c) 25 GHz (d) 30 GHz
52. For the dominant mode, in a rectangular waveguide with breadth 10 cm, the guide wavelength for a signal of 2.5 GHz will be
 (a) 12 cm (b) 15 cm
 (c) 18 cm (d) 20 cm
53. The degenerate modes in a wave guide are characterized by
 (a) Same cut-off frequency but different field distributions
 (b) Same cut-off frequency and same field distributions
 (c) Different cut-off frequency but same field distributions
 (d) Different cut-off frequencies and different field distributions
54. For TM waves in a parallel plate wave guide, the minimum attenuation arising from imperfect conductors would occur at a frequency of (f_c is the cut-off frequency)
 (a) $3f_c$ (b) $\sqrt{3}f_c$
 (c) $2f_c$ (d) $\sqrt{3}f_c$
55. For a rectangular wave guide ($a \times b$, $a > b$) to support only the TE_{10} mode at wave length which one of the following pairs of inequalities is to be satisfied?
 (a) $b < \lambda < 2b$; $\lambda > 2a$ (b) $b < \lambda < 2b$; $\lambda < 2a$
 (c) $a < \lambda < 2b$; $\lambda > 2a$ (d) $a < \lambda < 2b$; $\lambda < 2a$
56. The sinusoidally time-varying vector field

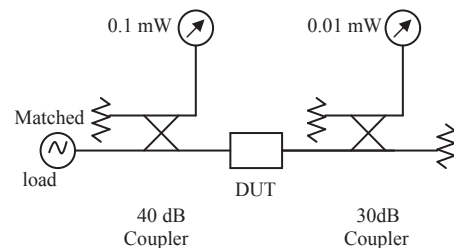
$$F = 2 \cos(\omega t + 30^\circ) \hat{a}_x + 2 \cos(\omega t - 30^\circ) \hat{a}_y$$
 is
 (a) Elliptically polarized (b) Circularly polarized
 (c) Linearly polarized (d) Unpolarized
57. The cut-off wavelength λ_c for TE_{20} mode for a standard rectangular wave guide is
 (a) $2/\alpha$ (b) 2α
 (c) α (d) $2\alpha^2$
58. A cylindrical cavity operating in TE_{111} mode has a 3 dB bandwidth of 2.4 MHz and its quality factor is 4000. Its resonant frequency would be
 (a) 9.6 GHz (b) $\frac{9.6}{\sqrt{2}}$ GHz
 (c) $\frac{9.6}{\sqrt{3}}$ GHz (d) $\frac{9.6}{\sqrt{3}}$ GHz
59. In a certain micro strip patch antenna the unexcited patch is of length L , width W , thickness of the substrate being h and its relative permittivity ϵ_r . Then the capacitance of the unexcited patch is
 (a) $\frac{LW}{\epsilon_r h}$ (b) $\frac{LW}{\epsilon_0 \epsilon_r h}$
 (c) $\frac{\epsilon_r LW}{h}$ (d) $\frac{\epsilon_0 \epsilon_r LW}{h}$
60. For a hollow wave guide, the axial current must necessarily be
 (a) A combination of conduction and displacement currents
 (b) Conduction current only
 (c) Time-varying conduction current and displacement current
 (d) Displacement current only
61. A cylindrical cavity resonates at 9 GHz in the TE_{111} mode. The bandwidth 3 dB is measured to be 2.4 MHz. The Q of the cavity at 9 GHz is
 (a) $\frac{9000}{2.4\sqrt{3}}$ (b) $\frac{9000}{2.4\sqrt{2}}$
 (c) $\frac{9000 \times 2.4\sqrt{3}}{\sqrt{2}}$ (d) $\frac{9000}{2.4}$
62. In the standing wave detector method for measuring a slightly mismatched load impedance, the distance from the load position to the nearest voltage minimum towards the generator is one-eighth of the guide wavelength. The load is
 (a) a capacitive impedance
 (b) 10 MHz
 (c) 1 GHz
 (d) 10 GHz
63. A cylindrical cavity resonator has diameter of 24 mm and length 20 mm. The dominant mode and the lowest frequency band are operated as
 (a) TE_{111} and X-band (b) TM_{111} and C band
 (c) TM_{011} and Ku-band (d) TM_{010} and X-band

64. Which of the following is not possible in a circular wave guide?
- (a) TE_{10} (b) TE_{01}
(c) TE_{11} (d) TE_{12}
65. The emission of an alpha particle from the nuclear of $^{226}_{88}Ra$ will yield
- (a) $^{223}_{86}Rn$ (b) $^{222}_{86}Rn$
(c) $^{222}_{88}Rn$ (d) $^{223}_{88}Rn$
66. The correct sequence of the assembled parts in klystron amplifier from any end is
- (a) Anode, catcher cavity, cathode and buncher cavity
(b) Cathode, buncher cavity, catcher cavity and anode
(c) Anode, buncher cavity, catcher cavity and cathode
(d) Cathode, catcher cavity, anode and buncher cavity
67. Consider the following statements:
If the narrow dimension of a standard rectangular wave guide carrying the dominant mode is reduced, then the
1. Wave impedance will increase
 2. Attenuation will increase
 3. Guide wavelength will decrease
 4. Power handling capability will decrease
- Which of these statements are correct?
- (a) 1 and 2 (b) 2 and 4
(c) 3 and 4 (d) 1 and 3
68. Consider the following parameters:
- A. Loss in the media
 - B. Permeability of the media
 - C. Frequency of the wave
 - D. Velocity of the wave
- Which of these parameters are responsible for the change of phase of a propagating electromagnetic wave?
- (a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1 and 4
69. As a result of reflections from a plane conducting wall. Electromagnetic waves acquire an apparent velocity greater than the velocity of light in space. This is called the
- (a) Velocity of propagation
(b) Normal velocity
(c) Group velocity
(d) Phase velocity
70. In parametric amplifiers used in microwave communication system, the gain is mainly restricted by
- (a) Ambient temperature (b) Pump frequency
(c) Pump bandwidth (d) Pump energy
71. The correct sequence of subsystems of Klystron amplifier as they appear in the direction of flow of the electron below is
- (a) Buncher cavity, Cathode, Collector, Catcher cavity
(b) Buncher cavity, Cathode, Catcher cavity, Collector
(c) Cathode, Buncher cavity, Catcher cavity, collector
(d) Cathode, Buncher cavity, Collector, Catcher cavity

72. For using as a local oscillator for frequency measurements, the most suitable microwave source would be
- (a) Travelling wave tube (b) Double cavity klystron
(c) Reflex klystron (d) Magnetron
73. Electromagnetic oscillations are sustained in a two-cavity klystron due to
- (a) Feedback of output to the input cavity in proper phase
(b) Feedback of output power to the input cavity with phase difference of 180°
(c) Feedback of power from external load to input cavity in proper phase
(d) Feedback of power from thermal noise of load circuit with phase lag of 90°
74. Consider the following features:
1. Wider bandwidth due to higher frequencies
 2. Smaller component size leading to smaller systems
 3. Existence of low signal losses
 4. Lower interference due to lower signal crowding
- Use of RF/microwave in system application results in which of these advantages?
- (a) 1, 2 and 4 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 4
75. The excitation of outer electrons in atoms and molecules is associated with which of the following bands of radiation?
- (a) X-rays (b) Gamma rays
(c) Ultra violet (d) Infrared

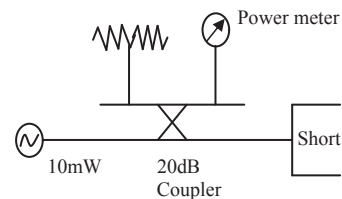
LEVEL 3

1. The insertion loss of the Device Under Test (DUT) shown in the given figure is



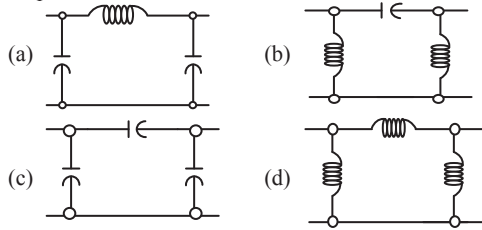
- (a) 10 dB (b) 20 dB
(c) 30 dB (d) 40 dB

2. In the measurement of microwave signal as shown in the given figure, the power metre reads $0.01 \mu W$. The coupler directivity is

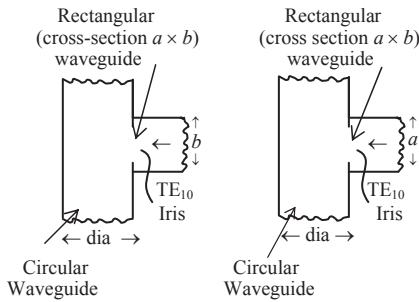


- (a) 20 dB (b) 30 dB
(c) 40 dB (d) 50 dB

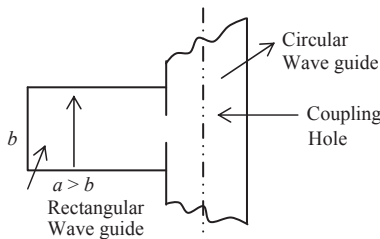
3. The equivalent circuit of a gap in the strip conductor of a micro strip is



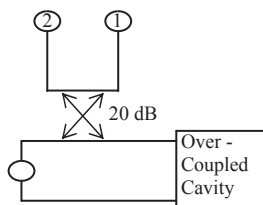
4. The propagation of TE_{10} mode in a rectangular wave-guide is used to excite a circular wave-guide as shown in figure I and figure II. The mode excited in the circular wave-guide of figure I and figure II will, respectively, be



- (a) TE_{11} and TM_{01}
 (b) TM_{01} and TE_{11}
 (c) TE_{01} and TM_{01}
 (d) M_{01} and TE_{01}
5. In a rectangular wave guide with broader dimension a and narrow dimension b , the dominant mode of microwave propagation would be
- (a) TE_{10}
 (b) TM_{10}
 (c) TE_{01}
 (d) TM_{01}
6. If TE_{10} mode propagates in the rectangular waveguide, which is the lowest mode excited in the circular wave guide?

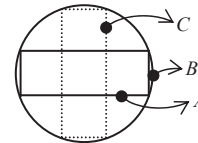


- (a) TE_{11}
 (b) TM_{11}
 (c) TE_{01}
 (d) tM_{01}
7. In the system shown below, the input VSWR is 1.5 at resonance. If the power metre 1 reads 1 mW, What is the reading on the power – metre 2?



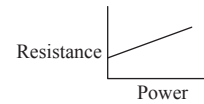
- (a) 0.1 m W
 (b) 0.06 m W
 (c) 0.04 m W
 (d) 0.02 m w

8. A rectangular waveguide (A) gradually deformed first into a circular waveguide (B) and back again into a rectangular waveguide (C) which is oriented through 90° with respect to (A). If the inputs mode is TE_{10} , which mode is excited in the output waveguide (C)?



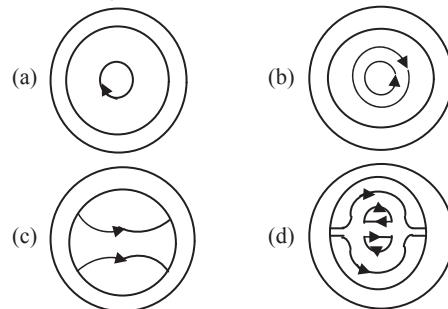
- (a) TE_{10}
 (b) TE_{01}
 (c) TE_{11}
 (d) TM_{11}

9. Figure shown the resistance versus power characteristics of

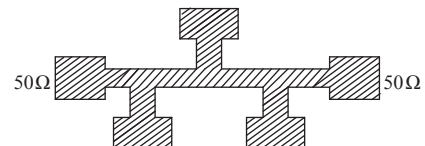


- (a) thermister
 (b) LDR
 (c) barrater
 (d) photodiode

10. Figure (a), (b), (c) and (d) given below represent of electric field of TE waves in wave guides. Which one of the them represents TE_{02} mode?

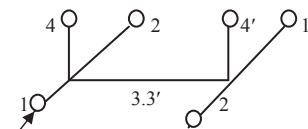


11. The following figure shown the conductor pattern of a micro strip-line version of a microwave filter. This represents a



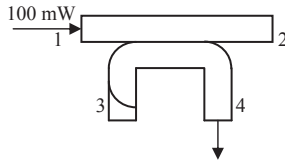
- (a) band pass filter
 (b) high pass filter
 (c) low pass filter
 (d) channel dropping filter

12. Two matched hybrid-T s are connected through two H-plane arms to form a 6-ports device (see figure given). If 4mW of power is fed into port 1 the output power (in-mW) in the other five ports, namely, 1', 2, 2', 4, 4', will be respectively



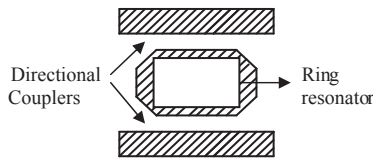
- (a) 0, 4, 0, 0, 0 (b) 1, 0, 1, 0, 2
(c) 1, 0, 1, 2, 0 (d) 0, 2, 1, 1, 0

13. With 100 mW input power, the power measured at port 4 is 0.1 mV and 10 mW. When port is terminated in a matched load and a short, respectively. The directivity of the coupler shown in the given figure is



- (a) 50dB (b) 40dB
(c) 30dB (d) 20 dB

14. What type of a device does the given figure micro-strip pattern represent?



- (a) Balanced mixer (b) Hybrid ring
(c) Channel dropping filter (d) Low pass filter

15. It is given that the first roots of $J_1(x) = 0$ and $J_1'(x) = 0$ are 3.83 and 1.84 respectively. Which one of the following gives the cut off wavelength of TM_{11} mode in a circular waveguide of diameter D ?

- (a) $\lambda_c \approx 0.64 D$ (b) $\lambda_c \approx 0.82 D$
(c) $\lambda_c \approx D$ (d) $\lambda_c \approx 1.2 D$

16. A 50 ohm coaxial line is connected to a 72 ohm load through a 60 ohm coaxial section of length 7.5 mm. What is the input VSWR on the line if it is fed by a 20 GHz source?

- (a) 1.0 (b) 1.25
(c) 1.33 (d) 1.44

17. A microstrip line of 50 ohm is terminated in $Z_L = 40 + j30\Omega$. What is the VSWR of the load?

- (a) 2.0 (b) 1.8
(c) 1.5 (d) 1.3

18. In an air filled waveguide of dimensions $a \text{ cm} \times b \text{ cm}$, at a given frequency, the longitudinal component of electric field of TM_{32} mode is of the form

$$E_z = 20 \sin(60\pi x) \sin(100\pi y)$$

Which form would E_z have for the lowest order TM mode?

- (a) $E_z = 20 \sin(20\pi x)$
(b) $E_z = 20 \sin(20\pi y)$
(c) $E_z = 20 \sin(20\pi x) \sin(50\pi y)$
(d) $E_z = 20 \sin(20\pi x) \sin(100\pi y)$

19. For a rectangular wave guide of dimensions $a = 3 \text{ cm} \times b = 1 \text{ cm}$, the cut off frequency for the TE_{10} mode is 2 GHz. What is the cut off frequency for TM_{11} mode in the waveguide?

- (a) 1 GHz (b) 3.46 GHz
(c) 4 GHz (d) 6 GHz

20. The Magic T (or Tee) is commonly used in mixing, duplexing and impedance measurement at microwave frequencies. it is characterized by a S-matrix given as

$$(a) \begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & S_{34} \\ S_{41} & S_{42} & S_{43} & 0 \end{bmatrix}$$

$$(b) \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & S_{24} \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

$$(c) \begin{bmatrix} 0 & 0 & S_{13} & S_{14} \\ 0 & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & 0 \\ S_{41} & S_{42} & 0 & 0 \end{bmatrix}$$

$$(d) \begin{bmatrix} S_{11} & S_{12} & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 \\ 0 & 0 & S_{33} & S_{34} \\ 0 & 0 & S_{43} & S_{44} \end{bmatrix}$$

21. A square wave-guide carries TE_{11} mode whose axial magnetic field is given by

$$H_z = H_0 \cos \frac{\pi x}{\sqrt{8}} \cos \frac{\pi y}{\sqrt{8}} \text{ A/m}$$

Where the wave-guide dimensions are in centimetres. What is the cut-off frequency of the mode?

- (a) 5 GHz (b) 7.5 GHz
(c) 6.5 GHz (d) 8 GHz

22. It is desired to reduce the reflection at an air porcelain by use of $(\lambda/4)$ plate. (for porcelain $\mu = \mu_0$ and $\epsilon_r = 7$). The thickness of the polystyrene plate required at 10 GHz will be

- (a) 5.039 cm (b) 50.39 cm
(c) 0.5039 cm (d) 0.05039 cm

23. An IMPATT diode has a drift length of 4 mm. The velocity of Si is 105 m/s. The operating frequency of the IMPATT diode is

- (a) 25 GHz (b) 20 GHz
(c) 12.5 GHz (d) 125 MHz

24. A rectangular wave guide measure $3 \times 4.5 \text{ cm}$ internally and has a 9 GHz signal propagated in it. The cut off wavelength for TE_{10} mode is

- (a) 5 cm (b) 10 cm
(c) 15 cm (d) 9 cm

25. One of the following microwave diodes is suitable for very low power oscillator only

- (a) Tunnel (b) Gunn
(c) IMPATT (d) LSA

ANSWER KEYS

LEVEL 1

1. (a)	2. (a)	3. (c)	4. (b)	5. (b)	6. (c)	7. (a)	8. (a)	9. (c)	10. (c)
11. (c)	12. (d)	13. (b)	14. (b)	15. (d)	16. (a)	17. (b)	18. (b)	19. (b)	20. (c)
21. (b)	22. (d)	23. (c)	24. (b)	25. (b)	26. (d)	27. (c)	28. (b)	29. (b)	30. (b)
31. (b)	32. (b)	33. (a)	34. (c)	35. (a)	36. (a)	37. (c)	38. (b)	39. (d)	40. (c)
41. (c)	42. (a)	43. (d)	44. (a)	45. (c)	46. (d)	47. (a)	48. (c)	49. (d)	50. (d)
51. (b)	52. (b)	53. (c)	54. (b)	55. (d)	56. (b)	57. (c)	58. (c)	59. (a)	60. (c)
61. (b)	62. (c)	63. (b)	64. (c)	65. (b)	66. (d)	67. (b)	68. (b)	69. (a)	70. (b)
71. (a)	72. (c)	73. (b)	74. (b)	75. (b)	76. (d)	77. (b)	78. (d)	79. (a)	80. (d)
81. (b)	82. (a)	83. (c)	84. (b)	85. (c)					

LEVEL 2

1. (c)	2. (b)	3. (c)	4. (d)	5. (d)	6. (d)	7. (a)	8. (c)	9. (b)	10. (c)
11. (a)	12. (a)	13. (a)	14. (c)	15. (b)	16. (d)	17. (c)	18. (a)	19. (b)	20. (b)
21. (c)	22. (c)	23. (c)	24. (c)	25. (c)	26. (a)	27. (d)	28. (a)	29. (d)	30. (c)
31. (a)	32. (d)	33. (a)	34. (c)	35. (d)	36. (b)	37. (b)	38. (d)	39. (b)	40. (c)
41. (c)	42. (a)	43. (d)	44. (d)	45. (a)	46. (b)	47. (d)	48. (b)	49. (a)	50. (b)
51. (a)	52. (a)	53. (c)	54. (d)	55. (d)	56. (c)	57. (c)	58. (a)	59. (c)	60. (d)
61. (b)	62. (d)	63. (b)	64. (a)	65. (b)	66. (b)	67. (a)	68. (b)	69. (d)	70. (b)
71. (c)	72. (c)	73. (a)	74. (a)	75. (c)					

LEVEL 3

1. (b)	2. (c)	3. (c)	4. (a)	5. (a)	6. (a)	7. (c)	8. (d)	9. (c)	10. (d)
11. (d)	12. (c)	13. (c)	14. (c)	15. (b)	16. (d)	17. (a)	18. (c)	19. (c)	20. (a)
21. (b)	22. (c)	23. (c)	24. (d)	25. (a)					

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CHAPTER

COMPUTER

ENGINEERING

12.1 NUMBER SYSTEMS

A group of four bits is called a **nibble** and a group of **eight bits** is known as a **byte**.

Basically we have four number systems that can be used to represent any information.

Characteristics of Commonly used Number Systems

Number System	Base of Radix (b)	Symbols Used (d_i or d_{-i})	Weight assigned to position $i - f$	Example
Binary	2	0, 1	2^i 2^{-f}	1011.11
Octal	8	0, 1, ..., 7	8^i 8^{-f}	3567.25
Decimal	10	0, 1, ..., 9	10^i 10^{-f}	3974.57
Hexadecimal	16	0, 1, ..., 9, A, ..., F	16^i 16^{-f}	3FA9.56

For binary number system, we have a different representation that can be used.

Sign-Magnitude Representation

Here the most significant bit specifies whether a number is +ve or -ve. If it is 0 then number is +ve. If it is 1 then number is -ve. If we have n bit to represent any number in sign-magnitude representation, the most significant bit will show the sign, so it can have a range of values as $[-(2^n - 1)]$ to $(2^n - 1)$.

For $n = 8$ bits

Values range between $-(2^8 - 1)$ to $(2^8 - 1)$ i.e., -127 to 127.

One's Complement Representation

In this case, representation of +ve will be the same as of sign-magnitude representation. To find the representation for -ve number, take the 1's complement of its corresponding +ve number representation.

In this case also, for n bits, value range from $-(2^n - 1)$ to $(2^n - 1)$, 1's complement is obtained by replacing 0 by 1 and 1 by 0.

Two's Complement Representation

In this case also, +ve number representation is the same as of sign-magnitude representation of +ve number, for -ve number representation. Take 2's complement of corresponding +ve number representation. For n bits, value range from -2^n to $2^n - 1$ i.e., for 8 bit, it range from -128 to 127.

12.2 DATA REPRESENTATION

Fixed Point Representation

- Fixed point method assumes that the binary point is always fixed in one position (i.e., either to the left of the register or the right of the register)
- A point in extreme left of the register makes the stored data a fraction.
- A binary point is extreme right makes the stored data an integer.
- In either case, binary point is not actually present, but its presence is assumed (to specify whether stored data is fraction or integer).

Floating Point Representation

- It uses another register (or can use some bit of the same register) to store a number that designates the position of the decimal point in the first register (which is the exponent part).
- A floating point number is said to be normalized if most significant digit of the mantissa is non-zero.

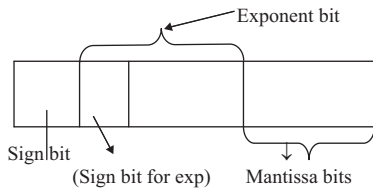


Fig. 12.1

Example: $(.1001110)_2 \times 2^{+4}$

- Here digit (bit in this case) after the decimal is non-zero so it is normalized.
- The figure shows that floating-point representation of a number has two parts. One part represents a signed fixed-point number called the mantissa. The other part shows the position of decimal (or binary) point and is called exponent (exponent will also have sign, so one bit of exponent specifies its sign).

12.3 PROGRAMMING

Programming Language

1. Low level PL
2. High level PL

Under low level PL, we have machine language (and) assembly language.

Pascal/C (actually middle level but we can say high level) C++, Java etc., these are high level languages.

Computer understands only machine language, so we need something that can transform the high level language program into machine language that is what is done by a compiler/assembler.

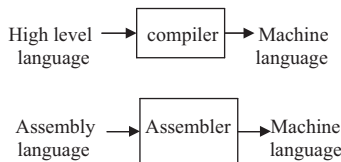


Fig. 12.2

12.4 FUNDAMENTALS OF COMPUTER ARCHITECTURE

Processor Design

- The heart of the processor is the processing unit that performs some operations. These operations can be arithmetic

operations or logical operations. ALU (Arithmetic Logic Unit handles this task).

- We can design arithmetic unit for performing various arithmetic operation like addition, subtraction, increment/decrement, transfer etc., using different adder/subtractor, multiplex circuit.
- Similarly, Parallel Logic Unit can be designed and these two units are combined to give ALU unit of processor.
- Processor also has a number of registers to perform various operations, e.g., PC (Program counter) register is used to keep track of next instruction that will be executed.

Control Unit

There are two major types of control organization:

Hard Wired Control

- In this, control logic is implemented with gates, flip-flops, decoder and other digital circuits.
- It has the advantage that it can be optimized to produce a fast mode of operation.

A hardware control requires changes in the wiring among the various components if the design is modified or changed.

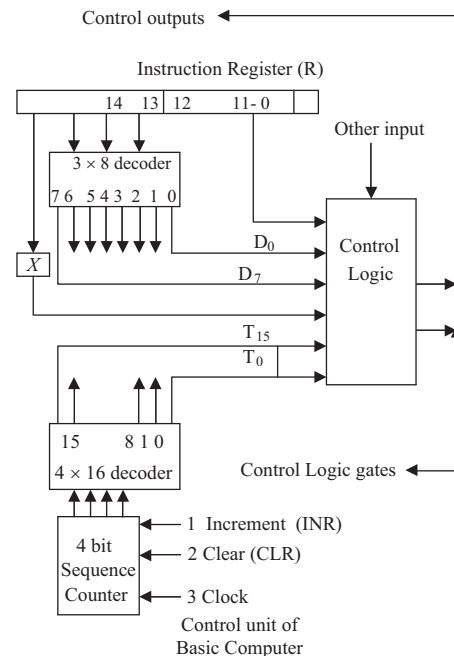


Fig. 12.3

Micro Programmed Control Unit

In this case, control information is stored in a control memory. The control memory is programmed to initiate the required sequence of operations (Micro-operations). In this case any required change or modification can be done by updating the micro program in control memory.

Micro-Programmed Control Organization

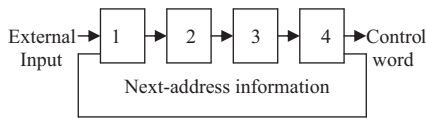


Fig. 12.4

Block Names

1. Next address generation (sequencer)
2. Control address register
3. Control memory (ROM)
4. Control data register.

The main memory is available to the user for storing the programs. The contents of main memory may alter when the data are manipulated and every time the program is changed. The user's program in main memory consists of machine instructions and data. In contrast, the control memory holds a fixed micro program that cannot be altered by the occasional user. The micro-program consists of micro-instructions that specify various internal control signals for execution of register micro-operations. Each machine instruction initiates a series of microinstructions in control memory. These micro-instructions generate the micro-operation to fetch the instructions from main memory; to evaluate the effective address, to execute the operation specified by the instruction, and to return control to the fetch phase in order to repeat that cycle for the next instruction.

Memory Organization

Integrated circuit RAM chips are available in two possible operating modes, static and dynamic. The static RAM consists essentially of internal flip-flops that store the binary information. The stored information remains valid as long as power is applied to the unit. The dynamic RAM stores the binary information in the form of electric charges that are applied the capacitors.

Bootstrap Loader

The ROM portion of main memory is needed for storing an initial program called a bootstrap loader. The bootstrap loader is a program whose function is to start the computer software operating when power is turned on. Since RAM is volatile, its contents are destroyed when power is turned off. The contents of ROM remain unchanged after power is turned off and on again. Thus when power is turned on, the hardware of the computer sets the program counter to the first address of the bootstrap. The bootstrap program loads a portion of the operating system from disk to main and control is then transferred to the operating system, which prepares the computer for general use.

Mapping

The transformation of data from main memory to the cache memory is referred to as a mapping process.

Three Types of Mapping Procedures

1. Associative mapping
2. Direct mapping
3. Set-associative mapping.

Associative Mapping

The fastest and most flexible cache organization uses an associative memory. The associative memory stores both the address and content (data) of the memory word. This permits any location in cache to store any word from main memory.

Direct Mapping

There are 2^k words in cache memory and 2^n words in main memory. The n -bit memory address is divided into two fields; k bits for the index field and $n-k$ bits for the tag field. The direct mapping cache organization uses the n -bit address to access the main memory and the k -bit to access the cache. Each word in cache consists of the data word and its associated tag. When a new word is first brought into the cache, the tag bits are stored alongside the data bits. The disadvantage of direct mapping is that the hit ratio can drop considerably if two or more words whose addresses have the same index but different tags are accessed repeatedly. However, this possibility is minimized by the fact that such words are relatively far apart in the address range.

Set-Associative Mapping

It was mentioned previously that the disadvantage of direct mapping is that two words with the same index in their address but with different tag values cannot reside in cache memory at the same time. A third type of cache organization, called set associative mapping, is an improvement over the direct-mapping organization in that each word of cache can store two or more words of memory under the same index address. Each data word is stored together with its tag and the number of tag-data items in one word of cache is said to form a set.

Hit Ratio

The performance of cache memory is measured in terms of a quantity called **Hit Ratio**. When CPU refers to memory and finds a word in cache, it is said to produce a hit, if word is not found, it is in main memory, it is called a miss. The ratio of the number of hits divided by total number of references of memory is the **Hit Ratio**.

Input/Output System Organization

There are four types of commands that an interface may receive. They are classified as control, status, data output and data input.

Control Command

A control command is issued to activate the peripheral and to inform it what to do.

Status

A status command is used to test various status conditions in the interface and the peripheral. For example, the computer may wish to check the status of the peripheral before a transfer is initiated. During the transfer, one or more errors may occur which are detected by the interface. These errors are designated by setting bits in a status register that the processor can read at certain intervals.

Output Data

A data output command causes the interface to respond by transferring data from the bus into one of its registers.

Input Data

The data input command is the opposite of the data output. In this case, the interface receives an item of data from the peripheral and places it in its buffer register.

First in First out Buffer

The important feature of this buffer is that it can input data and output data at two different rates and the output data are always in the same order in which the data entered the buffer. If the source is faster than the destination, the FIFO is useful for those cases where the source data arrive in bursts that fill out the buffer but the time between bursts is long enough for the destination unit to empty some or all the information from the buffer. Thus a FIFO buffer can be useful in some applications when data are transferred asynchronously.

Mode of Transfer

Data transfer to and from peripherals may be handled in one of three possible modes.

Programmed Input/Output

In this case CPU stays in a program loop until the Input/ Output unit indicates that it is ready for data transfer. This is time consuming process since it keeps processor busy needlessly.

Interrupt

The CPU responds to the **interrupt** signal by storing the return address from the program counter into a memory stack and then control branch to a service routine that processes the required I/O transfer. The way that the processor chooses the branch address of the service routine varies from one unit to another. In principle, there are two methods for accomplishing this, one is called vectored interrupt and the other, non-vectored interrupt. In a non-vectored interrupt, the branch address is assigned to fixed location in memory. In a **vectored interrupt**, the source that

interrupts supplies the branch information to the computer. This information is called the interrupt vector. A **priority interrupt** is a system that establishes a priority over the various sources to determine which condition is to be serviced first when two or more requests arrive simultaneously. **Establishing the priority** of simultaneous interrupt can be done by software or hardware. A polling procedure is used to identify the highest-priority source by software means. The disadvantage of the software method is that if there are many interrupt, the time required to poll them can exceed the time available to service the I/O device. In this situation a hardware priority-interrupt unit can be used to speed up the operation. A hardware priority-interrupt unit functions as an overall manager in an interrupt system environment. Thus no polling is required because all the decisions are established by the hardware priority-interrupt unit. The hardware priority function can be established by either a serial or a parallel connection of interrupt lines. The serial connection is also known as the daisy chaining method.

DMA

In DMA, the interface transfers data into and out of the memory unit through the memory bus. The CPU merely delays its memory access operation to allow the direct memory I/O transfer.

Input-Output Processor

An input-output processor (IOP) may be classified as a processor with direct memory access capability that communicates with I/O devices. The IOP is similar to CPU except that it is designed to handle the details of I/O processing. Unlike the DMA controller that must be set up entirely by the CPU, the IOP can fetch and execute its own instructions. IOP instructions are specifically designed to facilitate I/O transfers. In addition, the IOP can perform other processing tasks, such as arithmetic, login, branching, and code translation. The IOP provides a path for transfer of data between various peripheral devices and the memory unit. The CPU is usually assigned the task of initiating the I/O Program from then on the IOP operates independent of the CUP and continues to transfer data from external devices and memory.

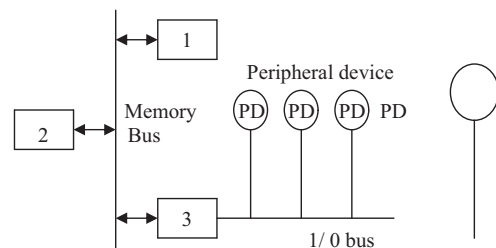


Fig. 12.5 Block Diagram of a Computer with I/O Processor

Block Name:

1. Central processing
2. Memory unit
3. Input-output processor (IOP)

Micro Processors Basic Terms

- The microprocessor can be viewed as a **programmable logic device** that can be used to control processes or to turn on/off devices.
- The microprocessor is a programmable integrated device that has **computing and decision-making capability** similar to that of the central processing unit (CPU) of a computer.
- The microprocessor communicates and **operates in the binary numbers 0 and 1** called **bits**.
- Each microprocessor has a fixed set of instructions in the form of binary patterns called a **machine language**.
- Instructions are given abbreviated names called **mnemonics**, which form the **assembly language**.
- A microprocessor is a multipurpose, programmable, clock-driven, register-based electronic device that reads binary instructions from a storage device called memory, accepts binary data as input and processes data according to those instructions, provides results as output.
- The physical components of this system are called hardware.
- A set of instructions written for the microprocessor to perform a task is called a **program**, and a group of programs is called **software**.

The microprocessor is in many ways similar to the CPU, but includes all the logic circuitry, including the control unit, on one chip. The microprocessor can be divided into three segments for the sake of clarity, as shown in below figure arithmetic/logic unit (ALU), register array, and control unit.

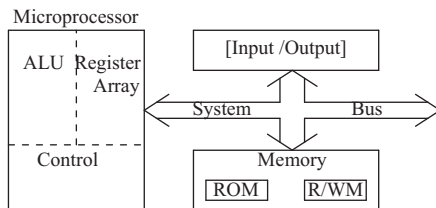


Fig. 12.6 Microprocessor Based with Bus Architecture

Arithmetic/Logic Unit

This is the area of the microprocessor where various computing functions are performed on data. The ALU unit performs such arithmetic operations as addition and subtraction, and such logic operations as AND, OR, and exclusive OR.

Register Array

This area of the microprocessor consists of various registers identified by letters such as B, C, D, E, H and L. These register are primarily used to store data temporarily during the execution of a program and are accessible to the user through instruction.

Control Unit

The control unit provides the necessary timing and control signals to all the operations in the microcomputer. It controls the flow of data between the microprocessor and memory and peripherals.

Memory

- Memory stores such binary information as instructions and data, and provides that information to the microprocessor whenever necessary to execute programs. The microprocessor reads instructions and data from memory and performs the computing operations in its ALU section. Results are either transferred to the output section for display or stored in memory for later use. The memory block shown in above figure has two sections: **Read-Only memory (ROM)** and **Read/write memory (R/WM)**, popularly known as **Random-Access memory (RAM)**.
- The ROM is used to store programs that do not need alterations.
- The Read/Write memory (R/WM) is also known as *user memory*: It is used to store user programs and data.

Input/Output

- **I/O includes two types of devices:** Input and output.
- These **I/O** devices are also known as peripherals. **ASCII** keyboard is found in most microcomputers (**PCs**).

System Bus

The system bus is a communication path between the microprocessor and peripherals; it is nothing but a group of wires to carry bits.

Instruction Set and Languages

The **word** (or word length) is defined as the number of bits the microprocessor recognizes and processes at a time.

A byte is defined as a group of eight bits. The term nibbles, which stands for a group of four bits. A byte has two nibbles.

Each machine has its own set of instructions based on the design of its CPU or of its microprocessor. To communicate with the computer, one must give instructions in **binary** language (**machine language**).

Programmers can write program called **assembly language programs** using English like words i.e., mnemonics.

An assembly language is specific to a given machine, programs written in assembly language are not transferable from one machine to another.

Low Level Languages

Machine language is in binary and the assembly language is in English like words i.e., in mnemonics.

The **assembler** is a program that translates the mnemonics entered by the ASCII keyboard into the corresponding binary machine codes of the microprocessor. Each microprocessor has its own assembler because the mnemonics and machine codes are specific to the microprocessor being used, and each assembler has rules that must be followed by the programmer.

High Level Languages

Programming languages that are intended to be **machine independent** are called **high level languages**. These include such languages as BASIC, PASCAL, C, C++ and java, all of which have certain sets of rules and draw on symbols and conventions from English Instructions written in these languages are known as **statements** rather than mnemonics.

Compiler or an Interpreter

These programs accept English like statements as their input called the **source code**. The compiler or interpreter then translates the source code into the machine language compatible with the microprocessor being used in the system. This translation in the machine language is called the **object code**. Each microprocessor needs its own compiler or an interpreter for each high level language.

- The compiler reads the entire program first and translates it into the object code that is executed by the microprocessor.
- The interpreter reads one instruction at a time, produces its object code (a sequence of machine actions) and executes the instruction before reading the next instruction.

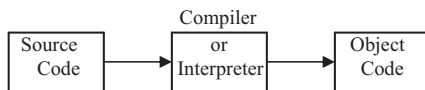


Fig. 12.7 Translation of High-Level Language Program into Machine Code

The primary advantage of high level languages is in troubleshooting (**debugging**) programs.

Operating Systems

The interaction between the hardware and the software is managed by a set of programs called an **operating system** of a computer; it oversees all the operations of the computer. The operating system is responsible primarily for storing information on the disk and for the communication between the computer and its peripherals.

The Floppy Disk

The floppy disk is a magnetic medium similar to a disk can be accessed randomly using disk drives.

Workstation

These are high-performance cousins of the personal computers. They are used in engineering and scientific applications such as Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), and Computer-Aided Manufacturing (CAM). They generally include system memory and storage (hard disk) memory in gigabytes, and a high-resolution screen.

The work stations are designed around RISC (reduced instruction set computing) processors (described). The RISC processor tend to be faster and more efficient than the processors used in personal computers. Some of the workstations have better performance than that of the low-end large computer.

12.5 8085 PROGRAMMING MODEL

The programming model consists of some segments of the ALU and the registers. This model does not reflect the physical structure of the **8085** but includes the information that is critical in writing assembly language programs.

Registers

The 8085 has **six general purpose registers** to store 8 bit these are identified as *B, C, D, E, H, and L*. They can be combined as register pairs BC, DE, and HL—to perform some 16 bit operations. The programmer can use these registers to store or copy data into the registers by using data copy instructions.

Accumulator

The accumulator is an 8 bit register that is part of the arithmetic/logic unit (ALU). This register is used to store 8 bit data and to perform some 16 bit operations. The result of an operation is stored in the accumulator. The accumulator is also identified as register A.

Flags

The ALU include **five flip flops** which are set or reset after an operation according to data conditions of the result in the accumulator and other registers. They are called Zero (Z) Carry (CY) Sign (S), Parity (P) and Auxiliary carry (AC) flags.

These flags have critical importance in the decision making process of the microprocessor. The conditions set or reset) of the flags are tested through software instructions.

The 8085 Flags

The following flags are set or reset after the execution of an arithmetic or logic operation: data copy instruction do not affect any flags.

- **Z-Zero:** The zero flag is set to 1 when the result is zero: otherwise it is reset.

- **CY-Carry:** If an arithmetic operation results in a carry, the CY flag is set; otherwise it is reset.
- **S-Sign:** The Sign flag is set if bit D_7 of the result = 1; otherwise it is reset.
- **P-Parity:** If the result has an even number of 1s, the flag is set; for an odd number of 1s the flag is reset.
- **AC-Auxiliary Carry:** In an arithmetic operation, when a carry is generated by digit D_3 and passed to digit D_4 , the AC flag is set. This flag is used internally for BCD (binary-coded decimal) operations: *there is no jump instruction associated with this flag.*

Program Counter (PC) and Stack Pointer (SP)

These are two 16-bit registers used to hold memory addresses.

The microprocessor uses the PC register to sequence the execution of the instructions. The function of the program counter is to point to the memory address from which the **next** byte is to be fetched. When a byte (machine code) is being fetched the program counter is incremented by one to point to the next memory location.

The **stack pointer** is also a 16-bit register used as a memory pointer. It points to a memory location in R/W memory, called the stack. The beginning of the stack is defined by loading a 16-bit address in the stack pointer.

1. **One byte instruction:** A mnemonic followed by a letter (or two letters) representing the registers (Such as A, B, C, D, E, H, L, M, and SP) is a one byte instruction.
Examples: (a) MOV A, B (b) DCX SP (c) RRC.
2. **Two byte instruction:** A mnemonic followed by 8-bits (byte) is a two byte instruction.
Examples: (a) MVI A, 8-bits (b) ADI 8 bits.
3. **Three byte instruction:** A mnemonic followed by 16-bit (also terms such as adr or dble) is a three byte instruction.
Example: (a) LXI B, 16-bit (dble) (b) JNZ 16 bit (adr).

Data Transfer (Copy) Instruction

These instructions perform the following six operations:

1. Load an 8-bit number in a register
2. Load 16-bit number in a register pair
3. Copy from register to register
4. Copy between register and memory
5. Copy between I/O and accumulator
6. Copy between register and stack memory.

Microprocessor Architecture and its Operations

This process of data manipulation and communication is determined by the logic design of the microprocessor, called the **architecture**.

- Microprocessor initiated operations
- Internal operations
- Peripheral (or externally initiated) operations.

The MPU Performs Primarily Four Operations

Memory Read: Reads data or instructions from memory.

Memory write: Writes data or instructions into memory.

I/O Read: Accepts data from input devices.

I/O Write: Sends data to output devices.

All these operations are part of the communication process between the MPU and peripheral devices (including memory). To communicate with a peripheral (or a memory location), the MPU needs to perform the following steps:

Step 1: Identify the peripheral or the memory location (With its address).

Step 2: Transfer binary information (data and instructions).

Step 3: Provide timing or synchronization signals.

Address Bus

The address bus is a group of 16 lines generally identified as A_0 to A_{15} . **The address bus is unidirectional:** bits flow in one direction—from the MPU to peripheral devices. The MPU uses the address bus to perform the first function: identifying a peripheral or a memory location (Step 1). In a computer system each peripheral or memory location is identified by a binary number called an address, and the address bus is used to carry a 16-bit address.

Data Bus

The data bus is a group of eight lines used for data flow. These lines are **Bi-directional:** Data flow in both directions between the MPU and memory and peripheral devices. The MPU uses the data bus to perform the second function: Transferring binary information (Step 2).

Control Bus

The control bus is comprised of various single lines that carry synchronization signals.

The MPU uses such lines to perform the third function: providing timing signals (Step 3). The term bus in relation to the control signals is somewhat confusing. This indicates an MPU operation. The MPU generates specific control signals for every operation it performs.

Internal Data Operations and the 8085 Registers

The internal architecture of the 8085 microprocessor determines how and what operations can be performed with the data. These operations are:

1. Store 8-bit data
2. Perform arithmetic and logical operations
3. Test for conditions
4. Sequence the execution of instructions
5. Store data temporarily during execution in the defined R/W memory locations called the stack.

Peripheral or Externally Initiated Operation

External devices (or signals) can initiate the following operations for which individual pins on the microprocessor chip are assigned Reset, Interrupt Ready, Hold.

Reset

When the reset pin is activated by an external key (also called a reset key) all internal operation are suspended and the program counter is cleared (it holds 0000H).

Interrupt

The microprocessor can be interrupted from the normal execution of instructions and asked to execute some other instructions called a service routine.

Ready

The 8085 has a pin called READY. If the signal at this READY pin is low, the microprocessor enters into a Wait state. The signal is used primarily to synchronize slower peripherals with the microprocessor.

Hold

When the **Hold** pin is activated by an external signal the microprocessor **relinquishes** control of buses and allows the external peripheral to use them. For example the **HOLD** signal is used in Direct Memory Access (DMA) data transfer.

Memory Classification

As mentioned earlier memory can be classified into two groups: **Prime** (system or main) **memory** and **storage memory**. The R/W M and ROM are examples of prime memory this is the memory the microprocessor uses in executing and storing programs. This memory should be able to respond fast enough to keep up with the execution speed of the microprocessor. Therefore, it should be random access memory, meaning that the microprocessor should be able to access information from any register with the same speed (Independent of its place in the chip). The size of a memory chip is specified in terms of bits for example a 1 K memory chip means it can store 1 K (1024) bits (not bytes). On the other hand, memory in a system such as a PC is specified in bytes. For example, 4M memory in a PC means it has 4 megabytes of memory.

The other group is the storage memory such as magnetic disks and tapes. This memory is used to store programs and results after the completion of program execution.

Flash Memory

This is a variation of **EE-PROM** that is becoming popular. The major difference between the flash memory and **EE-PROM** is in the erasure procedure. The **EE-PROM** can be erased at a register level but the flash memory must be erased either in its entirety or at the sector (block) level.

The 8085 Microprocessor

The 8085 is an 8-bit general purpose microprocessor capable of address 64 K of memory. The device has forty pins, requires a +5 V single power supply, and can operate with a 3 MHz signal phase clock.

Address Bus

The 8085 has 16 signal lines (pins) that are used as address bus however, these lines are split into two segments: $A_{15}-A_8$ and AD_7-AD_0 . The eight lines, $A_{15}-A_8$ are unidirectional and used for the most significant bits, called the high-order address, of 16-bit address. The signal lines AD_7-AD_0 are used for a dual purpose, as explained in the next section.

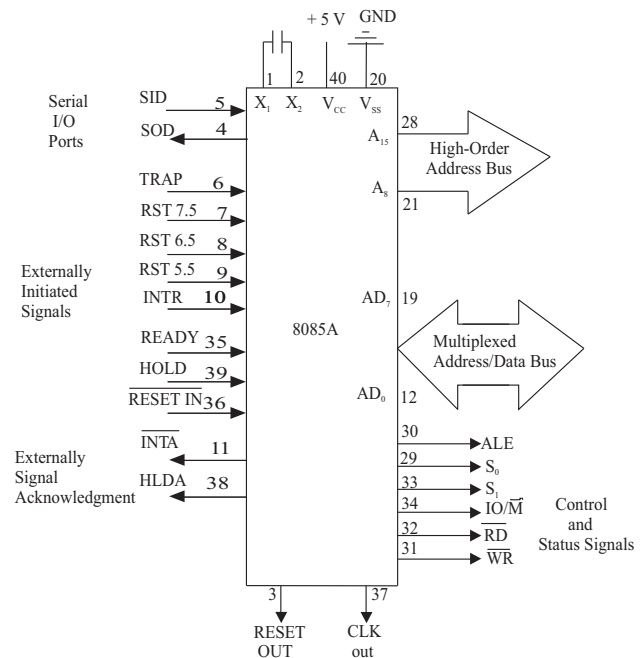


Fig. 12.8

Multiplexed Address/Data bus

The signal lines, AD_7-AD_0 are bi-directional: they serve a dual purpose. They are used as the low-order address bus as well as the low-order address bus. During the later part of the cycle, these lines are used as the data bus. (This is also known as multiplexing the bus). However, the low-order address bus can be separated from these signaled by using a latch.

Control and Status Signals

This group of signals includes two control signals ($\overline{RD}$ and $\overline{WR}$), three status signals ($IO/\overline{M}$, S_1 and S_0) to identify the nature of the operation and one especial signal (ALE) to indicate the beginning of the operation. These signals are as follows:

ALE—Address Latch Enable

This is a positive going pulse generated every time the 8085 begins an operation (machine cycle). It indicates that the bits on AD_7-AD_0 are address bits. This signal is used primarily to latch the low order address from the multiplexed bus and generate a separate set of eight address lines A_7-A_0 .

$\overline{RD}$ —Read

This is a Read control signal (active low). This signal indicates that the selected I/O or memory device is to be read and data are available on the data bus.

$\overline{WR}$ —Write

This is a write control signal (active low) this signal indicates that the data on the data bus are to be written into a selected memory or I/O location.

$IO/\overline{M}$

This is a status signal used to differentiate between I/O and memory signals operation.

S_1 and S_0

These status signals similar to IO/M can identify various operations but they are rarely used in small systems.

Power Supply and Clock Frequency

The power supply and frequency signals are as follows:

- V_{CC} : +5 V power supply
- V_{SS} : Ground reference.
- X_1, X_2 : A crystal (or RC, LC network) is connected at these two pins. **The frequency is internally divided by two;** therefore, to operate a system at 3 MHz, the crystal should have a frequency of 6 MHz.
- CLK (OUT)—Clock output: This can be used as the system clock for other devices.

8085 Interrupts and Externally Initiated Signals

- INTR (Input) $\Rightarrow$ **Interrupt Request**: This is used as a general purpose interrupt.
- $\overline{INTA}$ (Output) $\Rightarrow$ **Interrupt Acknowledge**: This is used to acknowledge an interrupt.
- RST 7.5/RST 6.5/RST 5.5 $\Rightarrow$ **Restart Interrupts**: These are vectored interrupts that transfer the program control to specific memory locations. They have higher priorities than the INTR interrupt. Among these three the priority order is 7.5 6.5 and 5.5.
- TRAP (Input) $\Rightarrow$ This is a non-maskable interrupt and has the highest priority.

- **HOLD (Input)** $\Rightarrow$ This signal indicates that a peripheral such as a DMA (direct Memory Access) controller is requesting the use of the address and data buses.
- **HLDA (Output)** $\Rightarrow$ **Hold Acknowledge**: This signal acknowledges the HOLD request.
- **READY (Input)** $\Rightarrow$ This signal is used to delay the microprocessor Read to send or accept data. When this signal goes low the microprocessor waits for an integral number of clock cycles until it goes high.

Various 8085 Operations/Cycle/Timing

Instruction cycle is defined as the time required to complete the execution of an instruction. The 8085-instruction cycle consists of one to six machine cycles or one to six operations.

- **Machine cycle** is defined as the time required to complete one operation of accessing memory, I/O or acknowledging an external request. This cycle may consist of three to six T-states.
- **T-state** is defined as one subdivision of the operation performed in one clock period. These subdivisions are internal states synchronized with the system clock, and each T-state is precisely equal to one clock periods. The terms T-state and clock period are often used synonymously.

RST (Restart) Software Instructions

The 8085 instruction set includes eight RST (Restart) instructions. These are 1-byte call instruction, that transfer the program execution are executed in a similar way to that of call instruction. The address in the program counter (meaning the address of the next instruction to an RST call instruction) is stored on the stack before the program execution is transferred to the RST call location. When the processor, the program returns to the address that was stored on the stack. In case of a hardware interrupt, we will use an RST instruction to restart the program execution.

8085 Vectored Interrupts

The 8085 has five interrupt inputs one is called INTR. Three are called RST 5.5, 6.5, and 7.5 respectively and the fifth is called TRAP a non-maskable interrupt. These last four RSTs and TRAP are automatically vectored (transferred) to specific locations on memory page 00H without any external hardware. They do not require the $\overline{INTA}$ signal or an input port the necessary hardware is already implemented inside the 8085. These interrupts and their call locations are as follows.

Interrupts	Call Locations
1. TRAP	0024H (4.5 × 8)
2. RST 7.5	003CH (7.5 × 8)
3. RST 6.5	0034H (6.5 × 8)
4. RST 5.5	002CH (5.5 × 8)

The **TRAP has the highest priority** followed by RST 7.5, 6.5, 5.5 and INTR in that order however the TRAP has a lower priority than the Hold signal used for DMA.

TRAP

TRAP is a *non-maskable interrupt* known as NMI. It has the highest priority among the interrupt signals, it need not be enable and it cannot be disabled. **It is level and edge sensitive** meaning that the input should go high and stay high to be acknowledged. It cannot be acknowledged again until it makes a transition from high to low to high.

When this interrupt is triggered, the program control is transferred to location 0024H without any external hardware or the interrupt enable instruction EI. TRAP is generally used for such critical events as power failure and emergency shunt-off.

RST 7.5, 6.5 and 5.5

These maskable interrupts are enabled under program control with two instruction : EI (Enable Interrupt) described earlier, and SIM (Set Interrupt Mask) described below:

RST 7.5

This is *positive edge sensitive* and can be triggered with a short pulse. The request is stored internally by the D flip-flop until the microprocessor responds to the request or until it is cleared by Reset or by bit D_4 in the SIM instruction.

RST 6.5 and RST 5.5

These interrupts are *level sensitive meaning* that the triggering level should be on until the microprocessor completes the execution of the current instruction. If the microprocessor is unable to respond to these requests immediately, they should be stored or held by external hardware.

Addressing Modes

An instruction format contains an Opcode or mnemonic field and an operand or address field. Typically, there may be two source addresses for manipulation of data and the third as destination address. Many times we economise by making one of the source addresses as destination. However, we would like to address a large number of memory locations. To achieve this objective, different address techniques are employed. They are:

1. Immediate	2. Direct
3. Indirect	4. Register
5. Register Indirect	6. Indexed
7. Relative	8. Stack

Handshake

From the procedures described above, it is clear that the MPU cannot just issue an address on the address bus following it up either by sending data or be ready to receive data from any of the peripherals at any instant of time as it may be already engaged. So a signal is sent to the peripheral to know its status. Common status signals are BUSY and READY.

Synchronization of transfer of data between MPU and external devices is called **Handshaking**. The Handshake control operates as follows:

1. The CPU interrogates the I/O module to check the status of the required device (peripheral).
2. The I/O module replies to the device status.
3. If free the peripheral sends the data and a DATA READY signal to the I/O port.
4. The CPU determines that DATA READY signal is active. A latch holds the DATA READY signal until the CPU reads it.
5. The CPU accepts the data and sends an DATA Accepted Signal (DACC) by way of acknowledgements.
6. DATA READ line is reset to be ready to receive further data.

For sending out data, the peripheral READY signal is sent to I/O module which is detected by the CPU. After sending an OUTPUT READY signal, data is fed is data bus to the peripheral at the completion of which acknowledgment is sent.

Buffering

Another important task of I/O port is buffering that is, matching memory and CPU to the peripheral. The data rates of various devices are:

Memory Mapped I/O

In this, some portion of the available memory address space is reserved for input/output devices, while the rest is for RAM/ROM. One major advantage is that *all the instruction types including arithmetic and logic operation as also the different addressing modes are available to I/O data transfer* in contrast to just two, IN and OUT, instructions of isolated I/O. Also data from any register can be moved to a port or data from a port can be moved to any register. In isolated I/O mode data to and from ports have be routed through the Accumulator.

Interrupt I/O

When the microprocessor is asked to communicate with the I/O ports we say that the microprocessor is servicing. When an external device seeks priority in the execution of a program, the current programme is completed, the next instruction in PC is pushed to the stack the interrupt program is executed and the completion of it, the processor returns to the execution or original program popped to the PC. The starting address for interrupt service routine is stored at the two special memory locations called interrupt vector, which is loaded into the PC after the next instruction PC is pushed to the stack.

Direct Memory Access (DMA)

In this type of I/O technique, the data is transferred to the memory from the external devices by passing the microprocessor. An interface chip called the DMA controller chip is used with the MP for transferring data via. DMA. *DMA is used for transferring*

blocks of data from the memory to the external device such as a cassette recorder. In this type the transfer of 1 byte of data typically requires 1 μ s.

The DMA controller chip must be able to perform READ and WRITE operation similar to a MPU:

1. The DMA controller chip puts the MPU in a Hold state by means of the HOLD control signal.
2. The MPU then stops executing the program and disconnects the address data and memory control lines from its bus by placing them on a high impedance state. The microprocessor is totally disabled during DMA.
3. The MPU sends a DMA acknowledge signal when the DMA takes control of the address bus and control bus to put data on the RAM from the I/O device.
4. When once the DMA completes transfer of data into or out of memory the DMA controller transfers back the control of the buses to the MPU by releasing the HOLD state.

Types of DMA

1. Block transfer DMA
 2. Cycle stealing DMA
 3. Interleaved DMA
1. In this, blocks of data are transferred from and to memory by the I/O device over the DMA.
 2. On the other hand if the quantum of data to be transferred is not much cycle stealing.
 3. DMA is used when data are transferred on a byte by byte basis by seizing a clock cycle of the microprocessor. This is accomplished by stopping the clock signal to the MP. This is done by using the INHIBIT terminal when a LOW on the terminal disables the clock.
 4. In this, blocks of data are transferred when the microprocessor is not connected to external devices and performs internal operations such as decoding and arithmetic-logic operations. Though this is complex, microprocessor is not stopped. With interleaved DMA, each data transfer includes 1 bytes per instruction cycle.

Micro Processor 8086

- The Intel 8086 is a 16-bit microprocessor that is intended to be used as the CPU in a microcomputer.
- The term 16-bit means that its arithmetic logic unit, its internal registers, and most of its instructions are designed to work with 16-bit binary words.
- The 8086 has a 16-bit data bus, so it can read data from or write data to memory and ports either 16-bit or 8 bits at a time.
- The 8086 has a 20-bit address bus, so it can address any one of 2^{20} , or 1,048,576, memory locations.
- Each of the 1,048,576 memory addresses of the 8086 represents a byte-wide location.
- Sixteen-bit words will be stored in two consecutive memory locations.

- If the first byte of a word is at an even address, the 8086 can read the entire word in one operation.
- If the first byte of the word is at an odd address, the 8086 will read the first byte with one bus operation.
- The main point here is that if the first byte of a 16-bit word is at an even address, the 8086 can read the entire word in one operation.

8086 Internal Architecture

The 8086 CPU is divided into two independent functional parts, the bus interface unit or BIU, and the execution unit or EU. Dividing the work between these two units speeds up processing.

The BIU sends out addresses, fetches instructions from memory, reads data from ports and memory, and writes data to ports and memory. In other words, the BIU handles all transfers of data and addresses on the buses for the execution unit.

The execution unit of the 8086 tells the BIU where to fetch instructions or data from, decodes instructions, and executes instructions.

The Execution Unit

The EU contains control circuitry which directs internal operations. A decoder in the EU translates instructions fetched from memory into a series of actions which the EU carries out. The EU has a 16-bit arithmetic logic unit which can add, subtract, AND, OR, XOR, increment, decrement, complement, or shift binary numbers.

Flag Register

A flag is a flip-flop which indicates some condition produced by the execution of an instruction or controls certain operation of the EU. A 16-bit flag register in the EU contains nine active flags. Six of the nine flags are used to indicate some condition produced by an instruction. For example, a flip-flop called the carry flag will be set to a 1 if the addition of two 16-bit binary numbers produces a carry out of the most significant bit position. If no carry out of the MBS is produced by the addition, then the carry flag will be a 0. The EU thus effectively runs up a “flag” to tell you that a carry was produced.

The six conditional flags in this group are the carry flag (CF), the parity flag (ZF), the sign flag (SF), and the overflow flag (OF). The names of these flags should give you hints as to what conditions affect them. Certain 8086 instructions check these flags to determine which of two alternative actions should be done in executing the instruction.

General-Purpose Registers

EU has eight general purpose registers, labelled AH, AL, BH, BL, CH, CL, DH, and DL. These registers can be used individually for temporary storage of 8-bit data. The AL register is also called the *accumulator*. It has some features that the other general-purpose registers do not have.

Certain pairs of these general-purpose registers can be used together to store 16-bit data words. The acceptable register pairs are AH and AL, BH and BL, CH and CL, and DH and DL. The AH-AL pair is referred to as the AX register, the BH-BL pair is referred to as the BX register, the CH-CL pair is referred to as the CX register, and the DH-DL pair is referred to as the DX register.

BIU The QUEUE

While the EU is decoding an instruction or executing an instruction which does not require the use of buses, the *BIU fetches up to six instruction bytes* for the following instructions. The BIU stores these prefetched bytes in a first-in-first-out register set called a queue. When the EU is ready for its next instruction, it simply reads the instruction bytes(s) for the instruction from the queue in the BIU. This is much faster than sending out an address to the system memory and waiting for memory to send back the next instruction byte or bytes. The process is analogous to the way a bricklayer's assistant fetches bricks ahead of time and keeps a queue of bricks line dup so that the bricklayer can just reach out and grab a brick when necessary. Except in the cases of JMP and CALL instructions, where the queue must be dumped and then reloaded starting from a new address, this pre-fetch-and-queue scheme greatly speeds up processing. Fetching the next instruction while the current instruction executes is called *pipelining*.

Segment Registers

The 8086, BIU sends out 20-bits addresses, so it can address any of 2^{20} or 1,048,576 bytes in memory. However, at any given time the 8086 works with only four 65,536-byte (64-Kbyte) segments within this 1,048,576-byte (1-Mbyte) range. Four segment registers in the BIU are used to hold the upper 16 bits of the starting addresses of four memory segments that the 8086 is working with at a particular time. The four segment registers are the code segment (CS) register, the stack segment (SS) register, the extra segment (ES) register and the data segment (DS) register.

These four segments might be positioned in memory at a given time. The four segments can be separated for small programs which do not need all 64 Kbytes – In each segment, they can overlap.

Instruction Pointer

The next feature in the BIU is the instruction pointer (IP) register. The code segment register holds the upper 16 bits of the starting address of the segment from which the BIU is currently fetching instruction code bytes. The instruction pointer register holds the 16-bit address, or offset, of the next code byte within this code segment. The value contained in the IP is referred to as an offset because this value must be offset from (added to) the segment base address in CS to produce the required 20-bit physical address sent out by the BIU. The CS register points to the base or start of the current code segment. The IP contains the distance

or offset from this base address to the next instruction byte to be fetched. Figure is added to the 16-bit segment base address in CS to produce 20-bit physical address. Notice that the two 16-bit numbers are not added directly in line, because the CS register contains only the upper 16-bits of the base address for the code segment. The BIU automatically inserts zeros for the lowest 4 bits of the segment base address.

If the CS register, for example, contains 348AH, the starting address for the code segment is 348 AOH. When the BIU adds the offset of 4214H in the IP to this segment base address, the result is a 20-bit physical address of 38AB4H.

An alternative way of representing a 20-bit physical address is the *segment base : offset form*. For the address of a code byte, the normal for this alternative form will be CS:IP. As an example of this, the address constructed in the preceding paragraph, 38AB4H, can also be represented as 348A:4214.

Register

A stack, remember, is a section of memory set aside to store addresses and data while a subprogram is executing. The 8086 allows to set aside an entire 64-Kbyte segment as a stack. The upper 16 bits of the starting address for this segment are kept in the stack segment register. The stack pointer (SP) register in the execution unit holds the 16-bit offset from the

The 8086 MOV Accesses Immediate and Register Data

In previous discussion of the 8086 BIU, we have described how the 8086 accesses code bytes using the contents of the CS and IP registers. We have also described how the 8086 accesses the stack using the contents of the SS and SP registers. The different ways in which a processor can access data are referred to as its addressing modes. In assembly language statements, the addressing mode is indicated in the instruction. We will use the 8086 MOV instruction to illustrate some of the 8086 addressing modes.

Immediate Addressing Mode

Suppose that in a program you need to put the number 437BH in the CX register. The MOV CX, 437BH instruction can be used to do this. When it executes, this instruction will put the immediate hexadecimal number 437BH in the 16-bit CX register. This is referred to as immediate addressing mode because the number to be loaded into the CX register will be put in the two memory locations immediately following the code for the MOV instruction. This is similar to the way the port address was put in memory immediately after the code for the input instruction in the three-instruction program.

A similar instruction, MOV CL, 48H, could be used to load the 8-bit immediate number 48H into the 8-bit CL register. You can also write instruction to load an 8-bit immediate number into an 8-bit memory location or to load a 16-bit number into two consecutive memory locations, but we are not yet ready to show you how to specify these.

QUESTION BANK

LEVEL 1

1. The frequency of the driving network connected between pins 1 and 2 of a 8085 chips must be
 - (a) equal to the desired clock frequency
 - (b) twice the desired clock frequency
 - (c) four times the desired clock frequency
 - (d) eight times the desired clock frequency

2. The 8086 arithmetic instructions work on
 1. Signed and unsigned numbers
 2. ASCII data
 3. unpacked BCD data

Select the correct answer using the codes given below

Codes:

(a) 1 and 2	(b) 2 and 3
(c) 1 and 3	(d) 1, 2 and 3

3. Which of the following are required for a multimedia PC?
 1. CD-ROM drive, speaker and sound card
 2. modem and network card
 3. hardware needed to display videos and animation
 4. software needed to display videos and animation

Select the correct answer using the codes given below

Codes:

(a) 1, 2 and 3	(b) 1, 2, 3 and 4
(c) 1, 2 and 4	(d) 1, 3 and 4

4. Effective address is calculated by adding or subtracting displacement value to
 - (a) immediate address
 - (b) relative address
 - (c) absolute address
 - (d) base address

5. Consider the following registers:

1. Accumulator and B register
2. B and C registers
3. D and E registers
4. H and L registers

Which of these 8-bit registers of 8085 μP can be paired together to make a 16-bit register?

(a) 1, 3 and 4	(b) 2, 3 and 4
(c) 1 and 2	(d) 1, 2 and 3

6. Consider the following instructions of 8085 μP :

1. MOV M, A	2. ADDC
3. MVI A, FF	4. CMP M

Which of these cause change in the status of **flag(s)**?

(a) 1 and 2	(b) 1, 2 and 3
(c) 3 and 4	(d) 2 and 4

7. The computer program which converts statements written in high level language to object code is known as

(a) Assembler	(b) compiler
(c) Disassembler	(d) operating system

8. The use of cache in a computer system increases the
 - (a) Available memory space for the program
 - (b) Available memory space for data
 - (c) Average speed of memory access
 - (d) Addressing range of CPU

9. Consider the following:

1. Input device
2. Arithmetic and logic unit
3. Control unit
4. Auxiliary memory
5. Main memory
6. Active hub

Which of these form part of CPU?

(a) 1, 4 and 6	(b) 2, 3 and 6
(c) 2, 4 and 5	(d) 2, 3 and 5

10. Which one of the following is not a characteristic of RISC processor design?

- (a) One instruction per cycle
- (b) Register-to-register operations only
- (c) Simply address modes
- (d) Register-to-memory operations only

11. The following micro operations are part of interrupt cycle of control units

1. $MAR \leftarrow \text{save-address}$
2. $PC \leftarrow \text{routine-address}$
3. $MBR \leftarrow (PC)$
4. $\text{Memory} \leftarrow (MBR)$

Which one of the following is the correct order of their occurrence?

(a) 1, 2 and 3	(b) 2, 3 and 1
(c) 2, 1 and 3	(d) 3, 1 and 2

12. Which of the following is not a characteristic of transparent DMA mode of I/O operation?

- (a) The external logic steals cycles from the CPU
- (b) The normal rate of execution is slowed down
- (c) Only one word can be transferred at a time
- (d) Data is transferred to/from memory directly

13. A typical cell, for a dynamic RAM can be implemented by using how many MOS transistors?

(a) Six	(b) Five
(c) One	(d) Two

14. The contents of accumulator in an 8085 microprocessor are altered after the execution of the instruction?

(a) CMPC	(b) CP13A
(c) ANISC	(d) ORAA

12.14 ■ Computer Engineering

15. In an 8085 microprocessor, after the execution of XRAA instruction
 - (a) The carry flag is set
 - (b) The accumulator contains FF_H
 - (c) The content of accumulator is shifted by one
 - (d) The zero flag is set
16. In the 8086 instruction ADD, DX, [BX] [CI], the addressing mode of source operand is
 - (a) Register
 - (b) Register Indirect
 - (c) Based
 - (d) Direct
17. The MODEM is used with a personal computer to do which of the following?
 - (a) Convert from serial to parallel and vice versa
 - (b) Convert signals between TTL and Rs 232 C Standard and vice versa
 - (c) Convert from digital to analog signals and vice versa
 - (d) To convert the computer to a long distance communication link
18. The technology used for display in PC note-books (lap-top computers) is
 - (a) Light Emitting Diodes display
 - (b) Liquid Crystal display
 - (c) CRT display
 - (d) Plasma display
19. Consider the following:
 1. Sign Flag
 2. Zero Flag
 3. Carry Flag
 4. Parity Flag
 Which of the above flag of 8085 get affected by the instruction SUB B?
 - (a) 1 and 2
 - (b) 1 and 3
 - (c) 3 and 4
 - (d) 1, 2, 3 and 4
20. Which of the following area included on the architecture of computer?
 1. Addressing modes, design of CPU
 2. Instruction set, data formats
 3. Secondary memory, operating system
 Select the correct answer using the codes given below.
Codes:
 - (a) 1 and 2
 - (b) 2 and 3
 - (c) 1 and 3
 - (d) 1, 2 and 3
21. The first machine cycle of an instruction is always
 - (a) A memory read cycle
 - (b) A fetch cycle
 - (c) An I/O read cycle
 - (d) A memory write cycle
22. In 8085 microprocessor the value of the most significant bit of the result following the execution of any arithmetic or Boolean instruction is stored in
 - (a) The carry status flag
 - (b) The auxiliary carry status flag
 - (c) The sign status flag
 - (d) The zero status flag
23. In a microprocessor when a CPU is interrupted, it
 - (a) Stops execution of instructions
 - (b) Acknowledges interrupt and branches of subroutine
 - (c) Acknowledges interrupt and continues
 - (d) Acknowledges interrupt and waits for the next instruction from the interrupting device
24. A ROM is to be used to implement a “squarer” which outputs the square of a 4-bit number. What must be the size of the ROM?
 - (a) 16 address lines and 16 data lines
 - (b) 4 address lines and 8 data lines
 - (c) 8 address lines and 8 data lines
 - (d) 4 address lines and 16 data lines
25. Which one of the following statements is correct?
 - (a) PROM contains a programmable ‘AND’ array and a fixed ‘OR’ array
 - (b) PLA contains a fixed ‘AND’ array and a programmable ‘OR’ array
 - (c) PROM contains a fixed ‘AND’ array and a programmable ‘OR’ array
 - (d) PLA contains a programmable ‘AND’ array and a programmable ‘NOR’ array
26. Consider the following statements:
 The advantage of cycle stealing in DMA is that
 1. It increase the maximum I/O transfer rate
 2. It reduce the interference by the DMA controller in the CPU’s memory access
 3. It is beneficially employed for I/O device with shorter bursts of data transfer
 Which of the statements given above are correct?
 - (a) 1 and 2
 - (b) 1 and 3
 - (c) 2 and 3
 - (d) 1, 2 and 3
27. Consider a function g which is taking a parametre f of type pointer to function?
 - (a) g can make modification in the definition of f and the change is visible after return from g
 - (b) g can dynamically test f can modify it
 - (c) Functionality of g gets customized through functionality of f
 - (d) f can dynamically test g and modify it
28. Consider the following statements:
 1. Cache memory is low cost and fast memory
 2. Cache memory is fast but costly memory
 3. Performance of cache during program execution is measured by hit ratio
 4. Cache size is very large
 Which of the statements given above are correct?
 - (a) 1 and 2
 - (b) 2 and 3
 - (c) 3 and 4
 - (d) 1 and 4
29. Consider the following statements:
 The SIM instruction outputs the contents of accumulator to define
 - (a) Interrupt mask bit
 - (b) Interrupt pending bit
 - (c) Serial input data line
 - (d) Serial output data line

Which of the statements given above are correct?

- (a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1 and 4

30. Consider the following statements:

1. MOSFET ROMs have much larger capacities than those of the BJT ROMs
2. BJT ROMs are faster than the MOSFET ROMs
3. BJT RAM memories can be static or dynamic

Which of the statements given above are correct?

- (a) 1 only (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

31. Consider the following statements. Intel Pentium-IV processor is designed to give

1. DVD authoring and MPEG 4 video
2. 3-D gaming and digital imaging
3. Superior performance for along music

Which of the statements given above are correct?

- (a) Only 1 and 2 (b) Only 2 and 3
(c) Only 1 and 3 (d) 1, 2 and 3

32. Which one of the following registers of 8085 microprocessor is *not* a part of programming model?

- (a) Instruction register (b) Memory address register
(c) Status register (d) Temporary data register

33. Which block replacement algorithm is *not* generally used in cache operation?

- (a) LIFO (b) FIFO
(c) LRU (d) Random

34. For which of the following devices, is DMA the most suitable?

- (a) Keyboard (b) Mouse
(c) Joy stick (d) Hard disk

35. Which one of the following is *not* correct about recursion?

- (a) Depth of stack is proportional to the depth of recursion
(b) Some of the recursive function can not be written as non-recursive one
(c) For some of functions, writing recursive version is easier than non-recursive version
(d) Recursive functions have terminating condition which limits the depth of recursion

2. If a RAM has 34 bits in its MAR and 16 bits in its MDR, then its capacity will be

- (a) 32 GB (b) 16 GB
(c) 32 MB (d) 16 MB

3. In 8086, if the content of the code segment register is 1FAB and the content of the IP register is 1041, then the effective memory address is

- (a) 1FBC0 (b) 304C
(c) FDB5 (d) 20B51

4. The 54/74164 chips an 8-bit serial-input-parallel-output shift register. The clock is 1 MHz The time needed to shift a 8-bit binary number into the chips is

- (a) 1 μ s (b) 2 μ s
(c) 8 μ s (d) 16 μ s

5. A Read/Write memory chip has a capacity of 64 k Bytes. Assuming separate data and address lines and availability of chip enable signal, what is the minimum number of pins required in the IC chip?

- (a) 28 (b) 26
(c) 24 (d) 22

6. A microprocessor has 24 address lines and 22 data lines. If it uses 10 bits of op code, the size of its. Memory Buffer Register is

- (a) 22 bits (b) 24 bits
(c) 32 bits (d) 14 bits

7. Consider the following program:

PUSH	a	POP	BX
PUSH	b	ADD	AX, BX
PUSH	c		
POP		AX	
POP		BX	
SUB		AX, BX	

The expression computed by the above program and stored in AX is

- (a) $a + b - c$ (b) $c + b - a$
(c) $c - b + a$ (d) $c - b - a$
(d) 2 4 3 1

8. Consider the Motorola 68008, 68010, 68012 and 68020 microprocessors. In systems that are severely constrained by the space available for the printed circuit board, it is better to use

- (a) 68008 (b) 68010
(c) 68012 (d) 68020

9. Consider the following features in an 8085 microprocessor system with memory mapped I/O

1. Input devices have 16-bit address
2. Input devices are accessed using IN and OUT instructions
3. There can be maximum of 256 input devices and 256 output device
4. Arithmetic and logic operations can be directly performed with the input data

LEVEL 2

1. Consider the following instructions executed in 8086:

```
PUSH AX ; AX has 20 Hex in it
PUSH BX ; BX has 43 Hex in it
POP AX;
ADD AX, BX
POP G
```

The value stored in G would be

- (a) 20 Hex (b) 43 Hex
(c) 54 Hex (d) 68 Hex

12.16 ■ Computer Engineering

Select the correct answer using the codes given below:

Codes:

- (a) 1, 2 and 4 (b) 1, 3 and 4
(c) 2 and 3 (d) 1 and 4

10. Given a 32-bit processor with 16 MB main memory, 32 kB 4-way set-associative on-chip cache and a cache block size (or line size) of 16 words. What is the total number of tag bits in the memory address format?
(a) 9 (b) 20
(c) 11 (d) 24
11. A particular parallel program computation requires 100 seconds when executed on a single processor. If 40 percent of this computation is 'inherently sequential', then what are the theoretically best elapsed times for this program running with 2 and 4 processor, respectively?
(a) 20 and 10 seconds (b) 30 and 15 seconds
(c) 50 and 25 seconds (d) 70 and 55 seconds

12. Consider the following statements;

The 8085 microprocessor will not enter into bus idle machine cycle whenever

1. INTR interrupt is recognized
2. RST x.5 is recognized
3. DAD rp instruction is executed

Which of the statement given above is/are correct?

- (a) 1 only (b) 2 only
(c) 1 and 2 (d) 2 and 3

13. Consider the following program:

```

                ORG      7000 H
BEGIN:  LXI      H, 7000 H
                MOVE    A, L
                ADD     H
                JM      END
                RST     O
END:      PCHL
                HLT

```

Which one of the following statements is correct?

- (a) The program will halt the processor
(b) The program will be repeated infinitely
(c) The program will branch to 0007 H after JM END
(d) The program will branch to 0000 H after JM END

14. Consider the following program intended to transfer a block of 5 bytes from A000H to 9000H

```

START:  LXI      B, 9000H
                LXI      H, A000H
                MVI      C, 05H
LOOP:   MOV     A, M
                STAX     B
                INX      B
                INX      H
                DCR      C
                JNZ      LOOP
                HLT

```

The above program will not work because

- (a) C register is used as counter
(b) DCR C instruction will not affect zero flag
(c) JNZ instruction is used instead of JZ
(d) The first two instructions in loop should have been LDAX B and MOV M, A

15. A disc rotates at a speed of 7200 rpm. it has 4000 cylinders, 16 surface and 256 sectors per track. What is the average latency time of the disk?
(a) 8.33 ms (b) 4.166 ms
(c) 41.66 ms (d) 4.33 μ s

16. What are the number of machine cycles n , and the types of machine cycles carried out for PUSH B?
(a) $n = 2$, fetch and memory write
(b) $n = 3$, fetch and 2 memory write
(c) $n = 3$, fetch, memory write and read
(d) $n = 3$, fetch and 2 memory read

17. The following sequence of instructions is executed by an 8085 micro processor

```

1000  LXI    SP, 27 FF
1003  CALL  1006
1006  POP    H

```

What are the contents of the stack pointer (SP) and the HL register pair after completion of execution of these instructions?

- (a) SP = 27 FF, HL = 1003
(b) SP = 27 FD, HL = 1003
(c) SP = 27 FF, HL = 1006
(d) SP = 27 FD, HL = 1006

18. Which one of the following pairs of 8086 microprocessor's interrupt is not correctly matched?

- (a) INT 0 : Divide by zero
(b) INT 1 : Single step
(c) INT 2 : Break point
(d) INT 4 : Overflow

19. If push and pop operation on a stack takes 1 unit time, how much time would it take to delete an element n^{th} position from bottom?

- (a) 1
(b) N
(c) n^2
(d) Cannot be determined from the given data

20. Which of the following instruction of an 8086 microprocessor uses the contents of a CX register as a counter?

1. LOCK
2. LOOP
3. ROTATE

Select the correct answer using the code given below

- (a) Only 1 and 2 (b) Only 1 and 3
(c) Only 2 and 3 (d) 1, 2 and 3

21. Consider the bit pattern 01010001. Which of the following has a Hamming distance of exactly 2 from this pattern?

- (a) 01010000 (b) 01010010
(c) 01010011 (d) 01010110

- 22.** If we use 3 bits in the instruction word to indicate if an index register is to be used and if necessary, which one is to be used, then the number of index registers to be used in the machine will be
 (a) 3 (b) 6
 (c) 7 (d) 8
- 23.** Which one of the following microprocessors has refresh logic for dynamic memory?
 (a) 6502 (b) INTEL 8085
 (c) Motorola MC 6800 (d) 7316
- 24.** The Address Bus of Intel 8085 is 16 bit and hence the memory which can be accessed by this address bus is
 (a) 1 k Byte (b) 16 k Bits
 (c) 32 k Bits (d) 64 k Bytes
- 25.** Which one of the following Arithmetic IE statements is invalid?
 (a) IF (M - N) 50, 60, 70
 (b) IF (A-I) 10, 15, 20
 (c) IF (A - B) 20, 30, 40
 (d) IF (A-4) 40, 40, 50

ANSWER KEYS

LEVEL 1

1. (b)	2. (d)	3. (d)	4. (d)	5. (b)	6. (d)	7. (b)	8. (c)	9. (b)	10. (d)
11. (a)	12. (b)	13. (a)	14. (c)	15. (d)	16. (c)	17. (c)	18. (b)	19. (d)	20. (a)
21. (b)	22. (c)	23. (d)	24. (d)	25. (c)	26. (d)	27. (c)	28. (b)	29. (b)	30. (d)
31. (d)	32. (d)	33. (b)	34. (d)	35. (d)					

LEVEL 2

1. (a)	2. (a)	3. (d)	4. (c)	5. (a)	6. (d)	7. (c)	8. (d)	9. (d)	10. (a)
11. (b)	12. (c)	13. (d)	14. (b)	15. (b)	16. (b)	17. (c)	18. (a)	19. (d)	20. (c)
21. (b)	22. (a)	23. (d)	24. (d)	25. (b)					

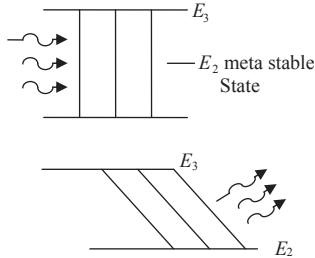
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SOLUTIONS

CHAPTER 1

LEVEL 1

- Dielectric strength should be high and dielectric loss should be low
-



E_2 (Meta stable state) is introduced by Cr ions

- When heated electrons away that and becomes positive other end will be negative.
- $q\eta\mu$ and $\mu = \frac{V_d}{E}$.
- The unit of mobility is $m^2V^{-1}s^{-1}$

$$\mu = -\frac{v_d}{E}$$

$$V_d \rightarrow \frac{\text{distance}}{\text{sec}} \text{ms}^{-1}, E = \frac{\text{Volt}}{\text{distance}} \text{Vm}^{-1}$$

- The Haynes-Shockley experiment enables one to determine the mobility of the minority carriers.

$$15. R_H = \frac{1}{nq}$$

The Haynes-Shockley experiment enables one to determine the mobility of the minority carriers.

$$19. M = (\mu_r - 1)H = \chi H$$

For superconductor, $\chi = -1$ as $\mu_r = 0$

For diamagnetic, $\chi_{\text{dia}} = -10^{-5}$
 χ_{para} is of the order of $+10^{-3}$ and $\chi_{\text{ferro}} \gg \chi_{\text{para}}$.

- GaAs is infrared emitter.

- The material which has the property of becoming electrically polarized in response to an applied mechanical stress is termed as **piezoelectric**.

- Magnetic cores required for RF applications have low hysteresis and eddy current losses.

- At high temperature and high humidity, condition of surrounding air, does electrochemical breakdown occur.

- Decreasing order of resistivity constant – monel metal german silver.

$$33. Na-11(2, 8, 1)$$

$$1s^2, 2s^2 2p^6, 3s^1$$

$\therefore$ Half as many state as the number of atoms

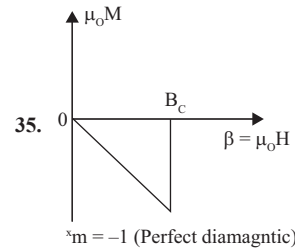
- Relaxation time $\propto$ the mean time of flight of electron between collisions.

$$\tau = \frac{m\sigma}{ne^2}$$

For perfect dielectric (insulator)

$$\sigma = 0$$

$$\therefore \tau = 0$$



$\chi_m = -1$ (Perfect diamagnetic)

In type I superconductor, as the applied magnetic field B increases, so does the opposing magnetization M until the field reaches the critical field B_c , where upon the superconductor behaviors is lost.

A Type I superconductor below B_c as in the Meissner state.

$$36. R_H = \frac{E_x}{B_z J_x}$$

$$= \frac{1}{q} \frac{(n_p \mu_p^2 - n_n \phi_p^2)}{(n_p n_n - \mu_n \mu_n)^2}$$

For intrinsic semiconductor

$$\eta_p = n_n = n_i$$

$$\mu_p < \mu_n$$

$$\Rightarrow R_H = \text{negative } V$$

- As the lattice temperature $\uparrow$
 Mobility of charge carrier $\uparrow$
 $\Rightarrow$ Hall coefficient $\downarrow$

S.2 ■ Solutions

38. Diamond → insulator

Si → Semiconductor

Nichrome → Metal

$$\frac{\text{Insulator} < s/c < \text{metal}}{\text{Resistivity}} \rightarrow$$

39. $E_i = \frac{E_o}{1 + \epsilon}$

41. Since the difference $E_F - E_V$ indicates how strongly the material is p+ve.

42. Residual resistivity mainly depends on impurity and it is given by

Nordheim's rule Specific resistivity of alloy

$$\rho_{\text{alloy}} = \beta x(1 - x)$$

Where, $\beta \rightarrow$ constant

$x \rightarrow$ fractional part of impurity in metal.

When $x \rightarrow$ is very small, $1 - x \approx 1$

$$\rho_{\text{alloy}} = \rho_r = \beta x$$

44. Magnetic susceptibility, $X_m = \mu_r - 1$. For paramagnetic materials, relative permeability μ_r is only lightly greater than unity, therefore X_m is only slightly greater than zero.

58. Schrodinger equation is

$$-\frac{\hbar^2}{2m} \cdot \frac{d^2\phi}{dx^2} + V\phi = E\phi$$

The wave vector ϕ governs the motion of electrons is the same say that light waves determine the motion of photons. In case of completely filled band, ϕ is zero, for the bound electrons are all confined to finite region. However, the total velocity of all the electrons in the band is not necessarily zero.

59. Crystallographic defects contributes to electron defects are thermal vibration, point defects and line defects.

60. From Curie-Weiss Law

$$\epsilon_r - 1 = \frac{C}{T - \theta}$$

Where ϵ_r = relative permittivity of the material

T = temperature of the material

C = Curie constant

θ = Curie temperature

The above relation represents neither a point nor a straight line or a parabola. Hence the curve is a cycloid.

61. Orientation polarization is inversely proportional to temperature and proportional to the square of the permanent dipole moment.

62. Resonance frequency for the fundamental lengthwise compression mode

$$f_r = \frac{1}{2l\sqrt{\rho s M}}$$

Where ρ is the density of the crystal.

63. Any charge injected into or released at point on the surface of a conductor, distributes itself on the surface of the conductor almost instantaneously so that the electric field at any point on the surface is entirely outward and normal to the surface and the field inside is zero effect indicates that, although superconductivity is an electronic phenomenon, it nevertheless depends in an important way on the vibrations of the crystal lattice in which the electrons move.

64. OC represents the coercive force for the Hysteresis loop shown in figure.

65. In intrinsic semiconductor, n_e and n_p are equal but $\mu_p < \mu_e$.

Conductor current flow is more due to holes. Thus, hall effect voltage is negative.

67. Superconductivity in a long circular wire or radius ' r ' may be destroyed when the current I exceeds the value I_c , which at the surface of the wire would produce the critical magnetic fields H_c .

Hence, as per expression, $H = \frac{1}{2} \pi a$, the current $I_c = 2 \pi H c$. This is referred to as Silbee's rule

82. Admittance

$$Y(s) = \frac{I(s)}{V(s)} = \frac{N(s) \rightarrow \text{Zeros}}{D(s) \rightarrow \text{Poles}}$$

It mean at pole frequency, $V = 0$

83. For transfer function realization separate rules are there, reactance function means only L and C but impedance represent combination of R , L , C .

84. $P = I^2 R = \frac{V^2}{R}$ is a non-linear response.

85. Series resonance is a low impedance resonance i.e. $Z_{in}(\omega)$ is a minimum.

$$\begin{aligned} 86. \cos \phi &= \cos \tan^{-1} \left(\frac{W_1 - W_2}{W_1 + W_2} \sqrt{3} \right) \\ &= \cos \tan^{-1} \sqrt{3} = 0.5 \end{aligned}$$

When the p.f is 0.5, one of the wattmeter reads zero and the other reads total power.

92. **BCS theory of Superconductivity**

The very low temperature, the amplitude of kinetic vibrations of electrons and atomic positive interactions producing photons which in turn interact with localized electron-spin pair coupling when the electrons rush towards positive ions. The binding energy between spin-locked

electrons is smaller than that for free-state electrons. At temperature below the critical temperature T_c the spin-pairing of valence electron would become more intensive. Such electrons are called super-electrons. Pairing is complete at $T = 0 K$ and it is completely broken at $T > T_c$. At extremely low temperatures, vibration of the nuclei atoms of centime slow down so much and they synchronies with the passing waves of electron-spin pair, in a flow of current. At this stage, resistance to electric current disappears and a little induced current form external battery, causes 60 A of current flow for several hours all by itself even when external battery is turned off. But external intense H-field can suppress superconductivity.

Now consider a lattice in which superconducting current exist, so that this current has a velocity $= -v$ with respect to lattice. But in collision events caused by impurities or phonons, the relative velocity v decreases if the relative velocity can generate electron-excisions of energy λ_k and momentum $\hbar_k$

95. Electrons are accelerated not holes which are not physical charge carriers.

97. The dielectric loses in the radio frequency region are usually due to dipoles rotation (i.e., oriental polarization) or to ions (i.e., ionic polarization) jumping from on e equilibrium position to another. But the losses in the optical region, are associated with the electrons (I. electronic Polaris ability)

99. The transition temperature of a superconductor can be reduced by the application of a magnetic field.

100. $\lambda = \frac{h}{p}$ where $p = mv$

101. Quartz

106. $E_i = \frac{E_{\text{applied}}}{1 - \frac{1.2a_e}{\pi \epsilon_0 a^3}}$

where a is inter atomic distance

107. where $K \rightarrow$ thermal conductivity
 $T \rightarrow$ electrical conductivity

LEVEL 2

4. Loss tangent $\tan \delta = \frac{\epsilon_{\text{img}}}{\epsilon_{\text{real}}}$

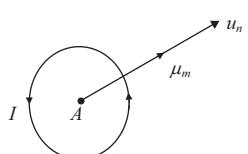
5. Thermal conductivity,

$$K = \frac{1}{3} \frac{n \pi^2 K^2 T \tau}{m}$$

6. $\mu = \frac{\sigma}{ne} = \frac{1}{\rho ne}$

9. $R_H = \frac{1}{ne}$ $\mu = \frac{1}{\rho ne} = \frac{R_H}{\rho}$
12. $N_a = 5 \times 10^{28}$ atoms/m³
Doping = 2 parts per million, i.e. 2×10^{-6}
Electron density = $2 \times 10^{-6} \times 5 \times 10^{28}$
= 10^{23} electrons/m³
13. Resistance $R = \frac{P}{I^2} = P I^{-2}$
Therefore $\frac{6R}{R}$
= $\pm \left(\frac{6P}{P} + 2 \frac{6I}{2} \right) = (1.5 + 2 \times 1.0)$
= $\pm 3.5\%$
14. $L \propto \frac{N^2 A}{F}$; $A \propto d^2$
 $L \propto \frac{N^2 d^2}{F}$
16. Young's modulus (Y) = $\frac{\text{stress}}{\text{strain}}$
stress = $Y \times \text{strain}$
= $\frac{Y \cdot \text{change in polarization}}{\text{Initial polarization}}$
= $\frac{130 \times 5}{550} \text{ GPa} = 1.182 \text{ GPa}$
20. Hall's constant is given by
 $R_H = \frac{1}{pq}$ or, $p = 1.25 \times 10^{15}/\text{cm}^3$
23. Resistance value when current in direction of l
 $R_1 = \frac{\rho l}{wt}$
Resistance value when the current in direction of w
 $R_2 = \frac{\rho w}{lt}$; Therefore $\frac{R_1}{R_2} = \frac{l^2}{w^2}$
24. Barium titanate (Ba Ti O_3) have relative permittivity ϵ_r between 3 to 6 and loss angle $\tan \delta$ between 5×10^{-4} to 100×10^{-4}
25. Sampling frequency should be at least twice of highest modulating frequency.
 $f_s \geq 2f_1$
For taking inverse the order charges
 $T_s = \frac{1}{f_s} \leq \frac{1}{2f_1}$
26. Energy gap for
1. Insulator $E_g \geq 5 \text{ eV}$
2. Semiconductor $0.1 < E_g < 5 \text{ eV}$
3. Conductor $E_g < 0.1 \text{ eV}$

27. $\lambda_c = \frac{1.24}{E_g} \mu\text{m} = \frac{1.24}{1.43} = 0.86 \mu\text{m}$
29. $\lambda \propto \frac{1}{\text{Energy of the electron}}$
Slow moving electron has low energy
30. **Second Method**
Fermi-Dirac probability function $f(E)$ is given by
$$f(E) = \frac{1}{1 + e^{(E-E_f)/kT}}$$

where E_f = Fermi level
If $E = E_f$ then $f(E) = \frac{1}{2}$ for any value of temp.
Thus the Fermi level represents the energy state with 50% probability of being filled if no forbidden band exists
31. At optical frequencies, the heavy ions cannot follow rapid field variations and ionic as well as orientation polarization vanishes
Second Method
Loss factor $\tan \delta = \frac{\epsilon''}{\epsilon'}$
32. $T_c = 4.12^\circ \text{K}$ with $H_c = 0$
33. Electrical resistivity has to be high for ferrites, not for 4% Si – Fe which is ferromagnetic material. Further, upon adding 4% Si coercive force and B_{sat} both decreases.
36. Magnetic dipole moment or magnetic moment
 $(\mu_m) = IA u_n$
 $u_n \rightarrow$ unit vector coming out of area A
- 
- = $IA = \frac{q}{t} A$
 $\mu_m = \frac{q}{t} \pi R^2 = \frac{q}{2} \frac{2\pi}{t} R^2$
 $\mu_m = 0.5 q \omega R^2$
37. $L = \mu_o n^2 A / \ell$
 $L \propto n^2$
Inductance L is proportional to n^2 i.e.,
 $\frac{L_1}{L_2} = \frac{n_1^2}{n_2^2}$

Hence on doubling the number of turns inductance becomes $L(2)^2 = 4L$.

38. $x_m = \frac{C}{T - T_c}$
i.e., $x_m \propto \frac{1}{T}$
 x_m = Magnetic susceptibility
 C = Curie constant.
Paramagnetic material (liquid oxygen) follow **Curie-Weiss law**.
39. **Yttrium-iron garnet** ($\text{Y}_2 \text{Gd}_{0.98} \text{Fe}_5 \text{O}_{12}$) are used in X-band (8 to 12 GHz) 3 port circulations handling high microwave powers.
40. $\frac{D}{\mu} = V_T$
 $\mu \times V_T = D$
 $D = \mu \times V_T$
= $0.4 \times 26 \text{ mV} = 0.4 \times 0.026$
= 0.0104
= 0.01.
41. Dielectric constant is very high up to 2000.
42. Electrical conductivity is measured in $\text{ohm}^{-1} \text{m}^{-1}$. Electrical conductivity of metals is 10^7 to 10^5 , of semiconductors, from 1 to 10^{-9} and of insulators 10^{-9} onwards. However, electrical resistivity is measured in terms of $\text{ohm} \cdot \text{m}$.
43. An alpha particle is a helium nucleus having atomic number 2 and mass number 4.
 ${}_{88}^{226}\text{Ra} \rightarrow {}_2^4\text{He} + {}_{86}^{222}\text{Rn}$.
48. $\left[\sigma = \frac{n e^2 \tau}{m} \right]$. On substituting the values, we get resistivity
= $\left[\frac{1}{\sigma} \right] = 1.73 \times 10^{-8} \Omega \text{m}$.
50. Relaxation time $\propto$ the mean time of flight of electron between collisions.
 $\tau = \frac{m\sigma}{ne^2}$
For perfect dielectric (insulator)
 $\sigma = 0$
 $\therefore \tau = 0$
51. $\sigma \propto \frac{1}{f}$
56. Loss tangent $\tan \delta = \frac{\epsilon_{\text{img}}}{\epsilon_{\text{real}}}$

S.4 ■ Solutions

57. Thermal conductivity,

$$K = \frac{1}{3} \frac{n \pi^2 K^2 T \tau}{m}$$

58. $\mu = \frac{\sigma}{ne} = \frac{1}{\rho ne}$

63. $R_H = \frac{1}{ne}$

$$\mu = \frac{1}{\rho ne} = \frac{R_H}{\rho}$$

64. Examples of Piezo Electric material

1. Quartz
2. Rochelle salt
3. Ammonium dihydrogen phosphate (ADP)
4. Barium Titanate (BaTiO_3)
5. Lead Titanate (PbTiO_3) Lithium sulphate
6. (LiSO_4)
7. Lead zirconate (PbZrO_3)

65. Since $n_e \cdot n_n = n_i^2$

For sample A: $n_e \cdot n_n = 1 \times 10^{20} \times 9 \times 10^8$
 $= 9 \times 10^{32}$

$\therefore n_i^2 = 9 \times 10^{20}$

For sample B: $n_e = 3 \times 10^{20}$ $n_n = \frac{n_i^2}{n_e}$

$$\frac{9 \times 10^{32}}{3 \times 10^{20}} = 3 \times 10^{12}$$

67. $V_H = -\frac{B_z I_x}{e n_e d}$

Where d is thickness of the crystal.

68. Instrument error arises due to three main reason

1. Due to inherent short coming in the instrument
2. Due to in misuse of the instrument
3. Due to loading effect

69. Systematic error remains constant or change according to definite law on repeated measurement of the given quantity. These error can be evaluated and their influence on the result of measurement can be eliminated by the introduction of proper connections.

70. The deflection of **hot wire instrument** depends on r.m.s value of the ac current

71. Manganin is used in the fabrication of **swamping resistance** of a PMMC instrument.

72. The basically a **current sensitive instrument** is permanent magnet moving coil instrument

73. electrostatic instruments can be used to determine the r.m.s value of ac **voltage of high magnitude** (10 kV) and of any wave shape

74. The battery cells in an electronic multimeter are required to measure the resistance.

76. An **electronic voltmeter** is more reliable as compared to multimeter for measuring voltages across low impedance because its sensitivity and input impedance are high and do not alter the measured value

78. A **data acquisition system** (DAS) is a group of electronics devices that are connected to perform the measurement and quantization of electrical signals for digital processing

LEVEL 3

- 1.

Case	Coordinate value	Miller
1 →	1, 0, 0 →	1, 00
2 →	[1/2], 0, 0 →	2, 00
3 →	1, 1, 0 →	1, 1, 0
4 →	1, 1, 1 →	1, 1, 1

2. As temperature increased critical magnetic field of superconducting material decreased.

$$H_c(T) = H_o \left(1 - \frac{T^2}{T_c^2} \right)$$

3. Voltage drop across a typical bead thermistor increases with increasing current until it reaches drop decreases as the current increases.

4. Intercepts on the respective axis are

$$\left(\frac{a}{2}, \frac{a}{2}, a \right)$$

Take reciprocal of intercept for miller indices

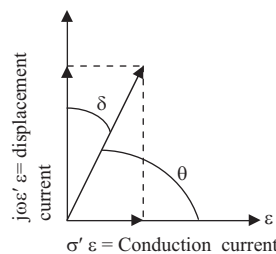
i.e. (2, 2, 1)

6. The new system has now two capacitor c in series

$$C = \frac{\epsilon A}{t} \quad C' = \frac{\epsilon A}{t/2} = \frac{2\epsilon A}{t} = 2C$$

New capacitance = 2C in series with 2C = C.

9. Time phase diagram of dielectric with losses.



Loss tangent = $\tan \delta = \frac{\sigma}{\omega \epsilon}$ [$\because \delta \rightarrow$ loss angle]

Power factor = $\cos \theta$; where $\theta = 90 - \delta$

Power dissipated per unit volume in dielectric

$$P = \frac{\text{Power}}{\text{Volume}} = \frac{I \times V}{A \times L} = J \cdot E$$

$$[\because I/A = J]$$

$$= \sigma E \cdot E = \sigma E^2$$

$$\tan \delta = 10^{-3}; f = 50 \text{ Hz}$$

$$\epsilon_r = 4.2 \quad E = 50 \text{ kV/cm}$$

$$\tan \delta = \frac{\sigma}{\omega \epsilon} = \frac{\sigma}{2\pi f \epsilon_o \epsilon_r}$$

$$10^{-3} = \frac{\sigma}{2\pi \times 50 \times \epsilon_o \times 4.2}$$

$$\sigma = 2\pi \times 50 \times \epsilon_o \times 4.2 \times 10^{-3}$$

$$\sigma = \pi \times \epsilon_o \times 4.2 \times 10^{-1}$$

$$= \pi \times 8.85 \times 10^{-14} \times 4.2 \times 10^{-1}$$

$$P = \sigma E^2$$

$$= \pi \times 8.85 \times 10^{-15} \times 4.2 \times (50 \times 10^3)^2$$

$$= 3.14 \times 8.85 \times 4.2 \times 10^{-15} \times 25 \times 10^8.$$

$$= 3.14 \times 8.85 \times 4.2 \times 25 \times 10^{-7}$$

$$= 3.14 \times 8.85 \times 4.2 \times 25 \times 10^{-4} \text{ mW/cm}^3$$

$$= 2917.8 \times 10^{-4} \text{ mW/cm}^3$$

$$= 0.29178 \text{ mW/cm}^3.$$

10. The actual field experienced by a molecule in a dielectric is defined as the local field E_{LOC} . E_{LOC} on the amount of polarizations.

The local field E_{LOC} acting on a molecule increase with polarization as

$$E_{LOC} = E + \frac{1}{j \epsilon_o} P$$

$$\text{Induced Polarization induced} = \alpha e E_{LOC}$$

$$P = X_e \epsilon_o E$$

$$\epsilon_r = 1 + X_e$$

$$P = (\epsilon_r - 1) \epsilon_o E$$

$$\frac{\epsilon_r - 1}{\epsilon_r + 1} = \frac{N \alpha_e}{j \epsilon_o}; \text{ this equation allows the calculation of macroscopic property.}$$

11. $\lambda = 8670 \times 10^{-10} \text{ m}$

$$h = 6.626 \times 10^{-34} \text{ J-s}$$

$$c = 3 \times 10^8 \text{ m/s}$$

$$\text{Eg (Joule)} = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{8670 \times 10^{-10}}$$

$$22.93 \times 10^{-20} \text{ joule}$$

$$\text{Eg (eV)} = \frac{22.93 \times 10^{-20}}{1.602 \times 10^{-19}} = 1.43 \text{ eV.}$$

$$12. E (\text{Vacuum}) = 2 \times 10^4 \text{ V/m}$$

When $\epsilon_r = 10$ then $E = ?$

$$E = \frac{V}{d}; \quad q = CV \Rightarrow V = \frac{q}{C}$$

$$C = \frac{\epsilon A}{d}$$

$$\Rightarrow C \propto \epsilon$$

$$V \propto \frac{1}{\epsilon}$$

$$\frac{E(\text{Vacuum})}{E(\text{dielectric})} = \frac{\epsilon_r}{\epsilon_o}; \text{ for } \epsilon_o = 1$$

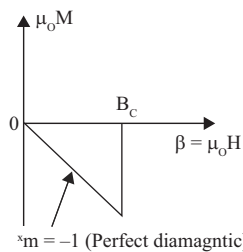
$$\therefore E(\text{dielectric}) = \frac{E(\text{Vacuum})}{\epsilon_r} = \frac{2 \times 10^4}{10}$$

$$= 2 \times 10^3 \text{ V/m.}$$

13. In type I super conductor, as the applied magnetic field B increases, so does the opposing magnetization M until the field reaches the critical field B_c , where upon the superconductor behaviors is lost.

A

A Type I superconductor below B_c as in the Meissures state.



14. Electrical conductivity of metals is of the order of 10^6 ohm^{-1} . For semiconductors $10^{-3} \text{ ohm}^{-1} \text{ m}^{-1}$ and for insulators 10^{-12} to $10^{-15} \text{ ohm}^{-1} \text{ m}^{-1}$

$$15. \text{ Resistance } R = \frac{P}{I^2} = P I^{-2} t$$

$$\text{Therefore } \frac{6R}{R}$$

$$= \pm \left(\frac{6P}{P} + 2 \frac{6I}{2} \right) = (1.5 + 2 \times 1.0)$$

$$= \pm 3.5\%$$

22. According to isotope effect, Superconducting transition temperature for a given element $\propto M^{-1/2}$

The vibration frequency of mass M on spring is proportional to $M^{-1/2}$ and the same relation holds for the characteristic vibration frequencies of the atoms in a crystal lattice. Thus the existences of the isotope effect indicates that, although superconductivity is an electronic phenomenon, it nevertheless depends in an important way on the vibrations of the crystal lattice in which the electrons move.

23. Flux density at all points, i.e. within the toroid core and in the air gap is practically same

$$\vec{H} = \frac{\vec{B}}{\mu}$$

Since $\mu > \mu_o$, $H_o > H_1$ and $\vec{B} \propto \vec{H}$ both are everywhere in direction i.e. H_o and H_1 have same directions.

$$24. N_a = 5 \times 10^{28} \text{ atoms/m}^3$$

Doping = 2 parts per million, i.e. 2×10^{-6}

$$\text{Electron density} = 2 \times 10^{-6} \times 5 \times 10^{28} = 10_{23} \text{ electrons/m}^3$$

$$25. \text{ Resistivity } \rho = \frac{m}{ne^2 \tau}$$

Where, m = mass of electron

n = Electron concentration

e = Electronic charge

τ = Relaxation time

$$\frac{\rho_B}{\rho_A} = \frac{\tau_A}{\tau_B} = \frac{2.7 \times 10^{-4}}{13.5 \times 10^{-4}} = 2.0$$

CHAPTER 2

LEVEL 1

3. As the intensity of illumination increases, more electron-hole pairs are formed. The conductivity increased and resistance reduces.

4. Gold is extensively used as a recombination agent by semiconductor device manufacturers. Thus the device designer can obtain desired carrier lifetimes by introducing gold in silicon under controlled conditions. Carrier life time range from nanoseconds ($1 \text{ ns} = 10^{-9}$) to hundreds of microseconds (μs).

Gold introduces a permissible energy level in the forbidden energy gap of silicon to reduce the recombination rate.

7. Light-Emitting Diodes.

Just as it takes energy to generate a hole-electron pair, so energy is released when an electron *recombines* with a hole.

- In silicon and germanium this *recombination* takes place through traps and the liberated energy goes into the crystal as heat.
- In gallium arsenide, there is a considerable amount of direct *recombination* without the aid of traps. Under such circumstance energy releases when an electron falls from the conduction into the valence band appears in the form of radiation. Such a p-n diode is called a light-emitter diode (LED), although the radiation is principally in the infrared.
- The efficiency of the process of light generation increases with the injected current and with decrease in temperature. The light is concentrated near the junction because most of the carriers are to be found within a diffusion length of the junction.

Under certain conditions, the emitted light is *coherent (essentially monochromatic)*. Such a diode is called an *injection junction laser*.

$$10. \mu_{Ge} = 3 \mu_{Si} \text{ and } \mu_n = 3 \mu_p.$$

13. Variations in the operating voltages of the voltages of the circuit are taken care of and hence these do not produce differential offset voltage.

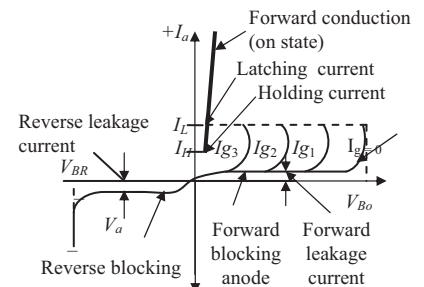
15. The current flow due to diffusion of carrier as there is no supply is connected.

$$16. f_T = \frac{g_m}{2\pi C_{b'e}}$$

When $C_{b'e}$ is diffusion Capacitance which is important high frequency.

17. As more electrons reach the collection junction and less recombination in the base region which result in I_c increases i.e., $\beta = \frac{I_c}{I_B}$.

22. It is SCR



23. Photolithography

During the photolithographic process the wafer is coated with uniform film of a photo sensitive emulsion. A large black-and-white layout of the desired pattern of openings is made and then reduced photographically. This negative, or stencil, of the required dimensions is placed as a mask over the photoresist, as or stencil.

1. By exposure of the **emulsion to ultraviolet (UV) light through the mask**, the photoresist becomes polymerized under the transparent regions of the stencil.
2. The mask is now removed, and the wafer is "**developed**" by using a chemical (such as trichloroethylene) which dissolves the unexposed (unpolymerized) portions of the photoresist film and leaves the surface pattern. The emulsion which was not removed in development is now fixed, or cured, so that it becomes resistant to the corrosive etches used next.
3. The chip is immerses in an **etching solution** of hydrofluoric acid, which removes the oxide from the areas through which dopants are to be diffuses. Those portions of the SiO_2 which are protected by the photoresist are unaffected by the acid.
4. After diffusion of impurities, the resist mask is removed (**stripped**) with a chemical solvent (such as hot H_2SO_4) coupled with a mechanical abrasion process. A negative photoresist is used in the process described above. Positive photoresists are also employed in which the exposed portion of the polymer is washed away and thus retains the unexposed material. The remainder of the processing steps are identical and independent of the type of photoresist used.

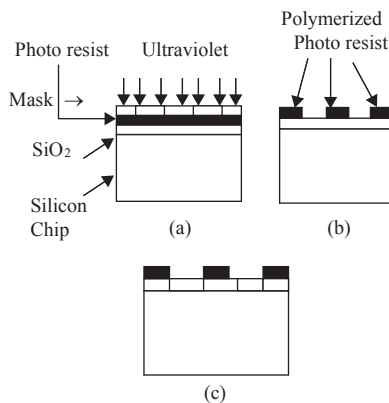


Figure: Photolithographic technique (a) Making and exposure to ultraviolet radiation. The photoresist after (b) Development and (c) Etching

26. Diode Resistance

For small-signal operation the dynamic, or incremental, resistance r is an important parameter, and is defined as the reciprocal of the slope of the volt-ampere characteristic $r = dV/dI$. The dynamic resistance is not a constant, but depends upon the depends upon the operating voltage. For example, for a semiconductor diode,

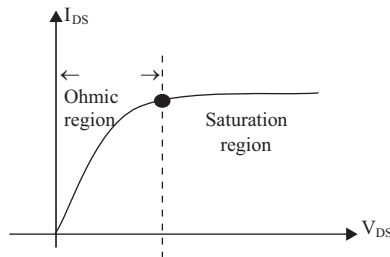
$$\text{we find that dynamic conductance } g = \frac{1}{r}$$

$$\text{is } g = \frac{dI}{dV} = \frac{I_o e^{V/\eta V_T}}{\eta V_T} = \frac{1 + I_o}{\eta V_T}$$

For a reverse bias greater than a few tenths of a volt (so that $|V/\eta V_T| \gg 1$), g is extremely small and r is very large. On the other hand, for a forward bias greater than a few tenths of a volt, $I \gg I_o$, and r is given approximately by $r \approx \frac{\eta V_T}{I}$.

The dynamic resistance varies inversely with current at room temperature and for ($\eta = 1$, $r = 26/I$), where I is in milliamperes and r in ohms. For a forward current of 26 mA, the dynamic resistance is 1Ω . The Ohmic body resistance of the semiconductor may be of the same order of magnitude or even much higher than this value. Although r varies with current, in a small-signal model, it is reasonable to use the parameter r as a constant.

28. According to Hall effect, a potential difference is developed across a current carrying metal strip when the strip is placed in a transverse magnetic field. Hall effect is very weak in metal, but is large in semi-conductors.
29. The characteristics of enhancement type MOSFET are shown in the figure.



30. The diffusion process takes place in two steps:
First, a high concentration of dopant is brought in contact with the surface of a silicon slice for a relatively short time, and
Second, the dopant source is removed and under the influence of high tempera-

ture, the dopant atoms on the slice surface penetrate the slice.

33. Donor impurity are Group-5 elements which are antimony (Sb), Phosphorus (P), Arsenic (As), Bismuth (Bi).
43. A push-pull amplifier may be operated as class-A, class-AB or class-B. When the large amounts of power are required, the amplifier is designed for class-B operation.
44. A Darlington pair circuit, has two emitter followers (cc - cc) in cascade. An emitter follower is the common collector circuit. In this case current gain is high $A_I = (1 + h_{fe}) h_{fe}$.
49. When temperature rises
n MOSFET $I_{D,sat} = 2C_i (V_g - V_T) V_s$
 $V_T = [KT/e]$
So, when temperature increase $-I_{DS}$ decreases
In transistor $I_C = \beta I_B + (1 + \beta) I_{CO}$.
 I_{CO} becomes double for every 10° rise in temperature
50. V_T = Threshold voltage
 N_D = Donor concentration
 C = Capacitance
 t = thickness = δ
 $V_T \propto \sqrt{N_D}$
 $V_T \propto \frac{1}{C} = \frac{1}{(\epsilon_o A)/d} \propto \frac{1}{t}$
 $V_T \uparrow \propto V_D \uparrow$ & $V_T \downarrow \propto t \uparrow$
51. In Zener diode, the carriers are accelerated by electric field. When they collide with atoms they ionize the atoms due to their kinetic energy. Hence an avalanche breakdown occurs due to the large increase in the number of carriers. Zener is heavily doped, similar to tunnel diode doping.
53. $V_{CE} = V_{BE} + V_{CB}$
As V_{CB} is increased, V_{CE} is pushed to the negative region, I_C starts even from the negative region and transistor operates in the reverse active mode i.e., collector junction, C_j is forward biased and Emitter junction E_j is Reverse biased i.e., reverse active mode.
56. By increasing the collector-base Reverse biased voltage the effective base width decrease before punch through phenomena. This is called **Early effect**.
57. MOSFET is field effect transistor where voltage control the flow the current.

MOSFET can be used as a resistor or capacitor. The insulating oxide layer between gate and channel form a parallel plate capacitor.

58. Ideally, the I_D is constant and independent of V_{DS} in saturation region.

In reality the I_D slightly increase in saturation region because the channel length is decrease on the drain junction is RB similarly as Base-width modulation.

59. n type is formed by doping with pentavalent impurity (P).

Others are G(4) and Al (3) B(3)

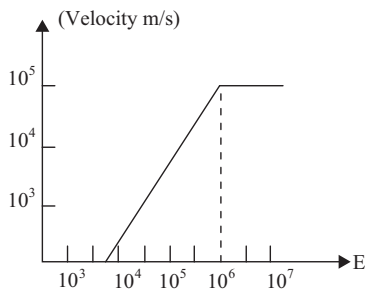
60. For JFET the drain current is given by the equation

$$I_D = I_{DSS} \left(1 - \frac{V_{GS}}{V_P} \right)^2$$

The above equation represented that the action of JEFT is voltage controlled current source.

61. Boron is an atom of Group III element, Group III elements are used for making p -type series conducts.

62. At high electric fields (E), velocity Saturation $\mu = \frac{V_d}{E} \propto \frac{1}{E}$ mobility decreases

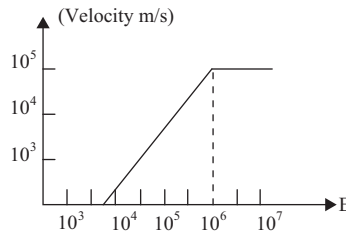


63. With increase in incident light intensity more pair of electrons and holes are generated. So current increase.

64. In a Junction diode
Depletion Capacitance
Reverse bias
 $CD \propto [1/\sqrt{(V_R)}]$
Diffusion Capacitance
Forward bias
 $C_o = [\tau I/V_f]$

66. Using $V_b = \frac{KT}{q} \ln \frac{N_A N_D}{n_i^2}$

67. At high electric fields (E), velocity saturates. $\mu = \frac{V_d}{E} \propto \frac{1}{E}$ mobility decreases



By theory $\vec{V}_n = E\mu_n$ where

$\vec{V}_n$ = drift velocity

E = applied electric field

μ_n = electron mobility

However, when the applied field is large the number of electrons in conduction band become very large and due to collisions the motion becomes erratic and the linear relationship becomes invalid, for $E > 10^6$ V/cm, Drift velocity value saturates.

68. The diffusion or barrier or junction potential is given by $V_B = \frac{KT}{q} \log e \left(\frac{N_A N_D}{n_i^2} \right)$

Where

V_B = Diffusion potential

q = Electron charge

N_A = Acceptor doping concentration in P material

N_D = Donor doping concentration in N material

n_i = Intrinsic carrier density

69. Because the emitter is the most heavily doped region in the transistor. It is about 40 to 50% of BV_{CBO} i.e., $BV_{CEO} < BV_{CBO}$ i.e., if doping is more then break up point is less.

71. A specimen of p -type semi conductor material is electrically neutral

72. P is connected to most negative potential available in the circuit, so that it majority holes be remain stable in p region.

74. In accumulation mode for N-MOS having P-substrate V_G is Negative. When negative V_G is applied to the gate, the hole in the type substrate are attracted to the semiconductor oxide interface. This condition is called carrier accumulation on the surface.

75. If it is extrinsic then $n + N_a = N_d + p$

for N-type----- $n = N_d$

So here $n, p = n_i^2$

$$p = [n_i^2/N_d]$$

n_i is constant for particular material at room temperature.

76. Under forward bias conduction the majority current flow i.e., drift current & under no bias conduction or low level injection the minority current flow i.e., diffusion current.

77. When $P^+ n$ junction diode is reverse biased the magnitude of field is maximum at Junction of $P^+ n$ i.e., lightly doped side i.e., the centre of the depletion region on the n -side.

78. n type is formed by doping with pentavalent impurity (P).

Others are G(4) and Al (3) B(3)

79. For a JEET in active region we have

$$I_{DS} = I_{DSS} \left(1 - \frac{V_{GS}}{V_P} \right)^2$$

From above equation, it is clear that the action of a JFET is voltage controlled current source.

80. Boron is an atom of Group III element, Group III elements are used for making p -type series conducts.

81. Photo Diode

It is a reverse bias semiconductor diode in which the electron hole pair are produced in or near the depletion region. As a result of high electric field exist in the depletion region, the carrier generated by incident light separate quickly into the majority regions before they recombine. Thus most of electro generated Paris contribute to the photo current.

Dark current as low as reverse saturation current.

The amount of absorption of light depend upon the frequency of the incident light and the intrinsic Semiconductor material.

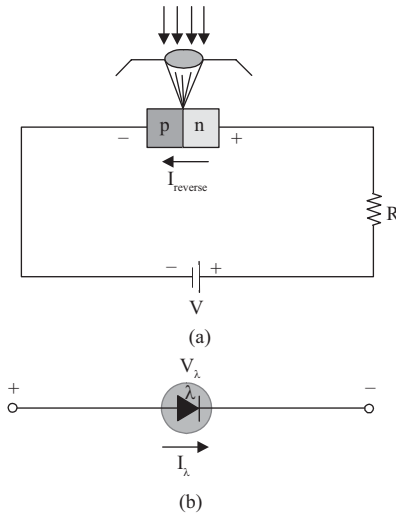
Energy carried by photon, $E = hf$

Band energy $= E_g$

When $hf \gg E_g$, Then sharp rise in absorption take place.

82. Covalent bonding

83.



Photodiode (a) basic biasing arrangement and construction (b) symbol

Photodiodes: If a reverse-biased pn junction is illuminated i.e., exposed to incident light the photons impacting the junction cause covalent bonds to break, and thus electron hole pairs are generated in the depletion layer. The electric field in the depletion region then sweeps the liberated electrons to the n side and the holes to the p side, giving rise to a reverse current across the junction. This current, known as **photo-current**, is proportional to the intensity of the incident light. Such a diode, called a photodiode, can be used to convert light signals into electrical signals.

Light-Emitting Diodes (LEDs)

The light-emitting diode (LED) performs that inverse of the function of the photodiode, it converts a forward current into light. The reader will recall that in a **forward-biased pn junction**, minority carriers are injected across the junction and diffuse into the p and n region. The diffusing minority carriers then recombine with the majority carriers. Such recombination can be made to give rise to light emission. This can be done by fabricating the pn junction using a semiconductor of the type known as **direct-bandgap materials**. Gallium arsenide belongs to this group and can thus be used to fabricate light-emitting diodes. The light emitted by an LED is proportional to the number of recombination that take place, which in turn is proportional to the forward current in the diode.

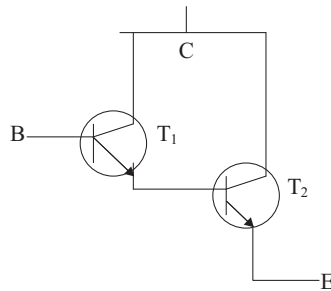
84. Early Effect/Base width modulation.

For active region operation of transistor collector base region is reversed biased.

Due to reverse bias the depletion width in base region increases which causes effective width of base to decrease. This effect is known as **early effect**. If the reverse bias V_{CB} is increased beyond a point, breakdown may occur as width of base becomes zero and phenomena is called **punch through**.

85. CC-CC (Darlington Pair)

The CC amplifier has high input impedance as a single transistor; to increase the input impedance still further we use the Darlington emitter follower, which is CC-CC amplifier. The two transistors form a composite pair. This can be considered as single transistor with only three external lead.



$$\frac{I_C}{I_{B1}} = h_{fe1} + h_{fe2} (h_{fe1} + 1)$$

Assuming two transistor is having same h_{fe}

$$\frac{I_C}{I_{B1}} = h_{fe} \times h_{fe} = h_{fe}^2; \quad A_v \cong 1$$

Input Impedance

$$R_i = h_{ie1} + (h_{fe1} + 1) h_{ie2}$$

$$R_i = 2h_{ie2} (h_{fe1} + 1)$$

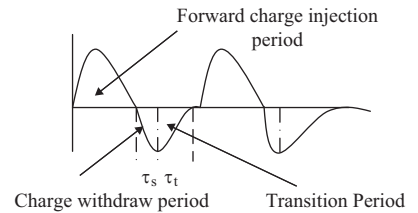
$$\text{assuming } h_{ie1} = h_{ie2} = h_{ie}$$

$\Rightarrow$ Darlington pair has very high input impedance and very low output impedance

86. • Region is completely free from any mobile charge. It behaves just like a Capacitor, which is controlled by applied voltage at P and N side.
- Forward bias causes Depletion region to shrink, so increase the value of capacitor.
- Total Depletion region width $W = W_n + W_p$
- $N_D W_n = N_A W_p$ means for highly doped region the Depletion region is less in that side.

87. Step Recovery Diode or Snap-back diode

Diffusion Capacitance arises because of the fact that the minority carriers are injected into one side of the junction during the forward bias excursion of the vector pump voltage (ac signal applied in parametric amplifier) and subsequently during the reverse bias portion of the wave form these charge carriers diffuse from the junction into the bulk material.



Use: higher order frequency multiplier (of order 8).

88. With increase in incident light intensity more pair of electrons and holes are generated. So current increase.

89. In a Junction diode

Depletion Capacitance

Reverse bias

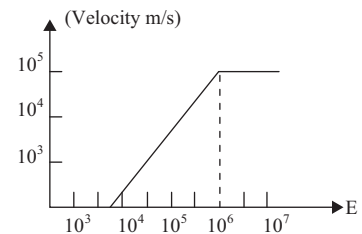
$$C_D \propto [1/\sqrt{V_R}]$$

Diffusion Capacitance

Forward bias

$$C_o = [\tau I/V_T]$$

91. At high electric fields (E), velocity saturates $\mu = \frac{V_d}{E} \propto \frac{1}{E}$ mobility decreases.



By theory $\vec{V}_n = E\mu_n$ where

$\vec{V}_n$ = drift velocity

E = applied electric field

μ_n = electron mobility

However, when the applied field is large the number of electrons in conduction band become very large and due to collisions the motion becomes erratic and the linear relationship becomes invalid, for $E > 10^6$ V/cm, Drift velocity value saturate.

92. The diffusion or barrier or junction potential is given by $V_B = \frac{KT}{q} \log e \left(\frac{N_A N_D}{n_i^2} \right)$

where

V_B = Diffusion potential

q = Electron charge

N_A = Acceptor doping concentration in P material

N_D = Donor doping concentration in N material

n_i = Intrinsic carrier density.

94. A specimen of p -type semiconductor material is electrically neutral.

95.

$$\text{Rise time } t_r = \frac{0.35}{f_H} = \frac{2.2}{2\pi f_H} = \frac{2.2}{W_H}$$

or

$$t_r = 0.35 T_p$$

where T_p is Pulse Width

96. P is connected to most negative potential available in the circuit, so that it majority holes be remain stable in p region.

LEVEL 2

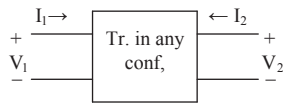
1. $n_i = 2.5 \times 10^{13} / \text{cm}^2$

$$n_n = 6.25 \times 10^{18} / \text{cm}^3$$

$$n_n \cdot n_p = n_i^2$$

$$\text{Hence } n_p = \frac{n_i^2}{n_n} = \frac{(2.5 \times 10^{13})^2}{6.25 \times 10^{18}} = 10^8 / \text{cm}^3.$$

3. Model: h – Para meter model



$$V_1 = h_{11} I_1 + h_{12} V_2$$

$$I_2 = h_{21} I_1 + h_{22} V_2$$

V_1 and $I_2 \rightarrow$ dependent Variable

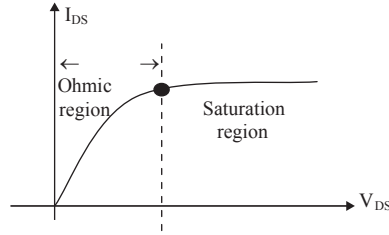
I_1 and $V_2 \rightarrow$ independent Variable

$$\begin{pmatrix} V_1 \\ I_2 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \begin{pmatrix} I_1 \\ V_2 \end{pmatrix}$$

$$h_i = h_{11} = \left. \frac{V_1}{I_1} \right|_{V_2=0}$$

$\Rightarrow$ Input impedance when output is s.c (Ω).

4.



6. In P -type semiconductor conductivity $\sigma_p = P \cdot e \cdot \mu_p$.

7. Diffusion constant $D = 100 \text{ cm}^2/\text{s}$
 $= 100 \times 10^{-4} \text{ m}^2/\text{s}.$

Life time $\tau = 100 \times 10^{-6} \text{ second}$

Hence diffusion length $L_D = \sqrt{(D\tau)}$
 $= \sqrt{100 \times 10^{-4} \times 100 \times 10^{-6}} = 0.1 \text{ cm}.$

11. $C_T = \frac{\epsilon A}{W}$

For Linearly junction capacitor $W \propto V_j^{1/3}$

For Step junction capacitor $W \propto V_j^{1/2}$.

14. $E = h \frac{C}{\lambda}$

$$\Rightarrow \frac{6.626 \times 10^{-34} \times 10^{-34} \times 10^8}{2.5 \times 1.6 \times 10^{19}} = \lambda = 4$$

15. $V_D = V_{ys} - V_p.$

18. Beam width $f_2 - f_1 = \frac{f_o}{Q} = \frac{10 \times 10^6}{1000}.$

19. $g_m = \frac{I_C}{V_T} = \frac{I_C q}{KT}$

Since $V_T = \frac{KT}{q}.$

20. Diode Resistance

For small-signal operation the dynamic, or incremental, resistance r is an important parameter, and is defined as the reciprocal of the slope of the volt-ampere characteristic $r = dV/dI$. The dynamic resistance is not a constant, but depends upon the depends upon the operating voltage. For example, for a semiconductor diode, we find that dynamic conductance

$$g = \frac{1}{r} \text{ is } g = \frac{dI}{dV} = \frac{I_o e^{V/\eta V_T}}{\eta V_T} = \frac{1 + I_o}{\eta V_T}$$

For a reverse bias greater than a few tenths of a volt (so that $|V/\eta V_T| \gg 1$),

g is extremely small and r is very large. On the other hand, for a forward bias greater than a few tenths of a volt, $I \gg I_o$, and r is given approximately by $r \approx \frac{\eta V_T}{I}.$

The dynamic resistance varies inversely with current at room temperature and for ($\eta = 1$, $r = 26/I$), where I is in milliamperes and r in ohms. For a forward current of 26 mA, the dynamic resistance is 1Ω. The Ohmic body resistance of the semiconductor may be of the same order of magnitude or even much higher than this value. Although r varies with current, in a small-signal model, it is reasonable to use the parameter r as a constant.

21. For JFET we know that

$$I_{DS} = I_{DSS} \left(1 - \frac{V_{GS}}{V_P} \right)^2 \quad (1)$$

$$\frac{\partial I_{DS}}{\partial V_{GS}} = I_{DSS} 2 \left(1 - \frac{V_{GS}}{V_P} \right) \times \left(-\frac{1}{V_P} \right)$$

$$g_m = \frac{-2 I_{DSS}}{V_P} \left(1 - \frac{V_{GS}}{V_P} \right) \quad (2)$$

g_{mo} = It is the value of g_m for $V_{GS} = 0$ and it is given by

$$g_{mo} = -\frac{2 I_{DSS}}{V_P} \quad (3)$$

Now

$$g_m = g_{mo} \left(1 - \frac{V_{GS}}{V_P} \right) \quad (4)$$

From equation (1)

$$\left(1 - \frac{V_{GS}}{V_P} \right) = \sqrt{\frac{I_{DS}}{I_{DSS}}} \quad (5)$$

From equations (2) and (5)

$$g_m = \frac{-2 I_{DSS}}{V_P}$$

$$= \sqrt{\frac{I_{DS}}{I_{DSS}}}$$

$$= \frac{-2}{V_P} \sqrt{I_{DS} \cdot I_{DSS}}$$

$$|g_m| = \frac{2}{|V_P|} \sqrt{I_{DS} \cdot I_{DSS}}$$

23. The cross-section of a typical integral junction capacitor is shown in the figure. The capacitor is formed by diffusing P -type impurities into an isolated island of the N -type epitomical layer. This defection is usually done simultaneously with the base diffusion transistors.

29. $\text{CMRR (db)} = 20 \log \frac{A_{DM}}{A_{CM}} = 80$

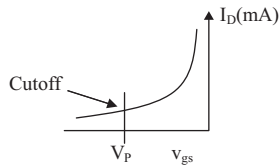
Or $\log \frac{A_{DM}}{A_{CM}} = 4$

Or $\frac{A_{DM}}{A_{CM}} = 10^4$

$\therefore A_{CM} = \frac{2 \times 10^4}{10^4} = 2$

30. $I_{DS} = I_{DSS} [1 - (V_{GS}/V_p)]$ i.e., at $V_{GS} = 0$, I_{DS} is maximum possible.

36.



Give, $V_p = 5.0V$

At, cutoff voltage, the drain current becomes zero

$$i_D = I_{DSS} (1 - V_{GS}/V_p)^2$$

Or, $0 = (1 - V_{GS}/V_p)^2$

Or, $V_{GS} = V_p$

37. FET operate on negative biasing voltage. When it maximum conduct i.e., in ON state. It have minimum resistance. $V_{gs} = 0$. For minimum ON resistance, V_{DS} should be maximum = $20V$

38. $V_{T(\text{new})} = V_{T(\text{old})} + [q F_B / C_i]$

Where $C_i = [\epsilon A / d] = \frac{3.9 \times 8.854 \times 10^{-14}}{400 \times 10^{-8}}$

$\therefore -1$

$$= 1 + \frac{1.6 \times 10^{-19} \times F_B \times 3.9 \times 8.854 \times 10^{-14}}{400 \times 10^{-8}}$$

Or, $F_B = -\frac{2 \times 3.9 \times 8.854 \times 10^{-14}}{1.6 \times 10^{-19} \times 400 \times 10^{-8}}$
 $= -1.08 \times 10^{12}/\text{cm}^2$

Threshold voltage V_T is always negative for p channel, hence p type.

39. Composite FET having, 2 identical FET's connected in parallel with g_m and rd is characterized by $2g_m$ and $rd/2$

40. $g_m = \frac{-2I_{DSS}}{V_p} \left(1 - \frac{V_{GS}}{V_p} \right)$
 $= -\frac{2 \times 2 \times 10^{-3}}{-4} \left(1 - \frac{(-2)}{(-4)} \right) = 0.5 \times 10^{-3}$

41. $i_D = I_o \exp [(V_D/nV_T) - 1]$
 $\cong I_o \exp [V_D/nV_T]$

$$\frac{i_D}{I_o} = \exp [V_D/nV_T]$$

$$\log e \frac{i_D}{I_o} = \frac{V_D}{nV_T}$$

or, $V_D = n V_T \log e [i_D/I_o]$

$$V_D \propto V_T \propto T$$

$$\frac{V_{D1}}{V_{D2}} = \frac{T_1}{T_2} = \frac{293}{313}$$

$$V_{D2} = 700 \times \frac{313}{293} = 747$$

42. $J_n = +q D_n [dn/dx] \cong$

$$\cong [1.6 \times 10^{-19} \times 35 \times 10^{-4}] \times \frac{(6 \times 10^{16} - 10^{+17})}{2 \times 10^{-6}}$$

$$= 1.6 \times 10^{-19} \times 35 \times 10^{-4} \times [4/2] \times 10^{22}$$

$$= +1120 \text{ A/cm}^2$$

43. $V_T = 300 \text{ K}$

$I = 1 \text{ mA}$

For Si, $I = I_o \text{Si} [\exp V/nV_T - 1]$; $n = 2$ for Si

$$1 \text{ mA} = I_o \text{Si} [\exp \frac{0.718}{2 \times 0.03} - 1]$$

For, Ge $I = I_o \text{Ge} [\exp \frac{0.1435}{1 \times 0.03} - 1]$

$$\frac{I_o \text{Ge}}{I_o \text{Si}} = I_o \text{Ge} \exp \left(\frac{0.1435}{1 \times 0.03} - 1 \right)$$

$$= I_o \text{Si} \left(\exp \frac{0.718}{1 \times 0.03} - 1 \right)$$

$$\frac{I_o \text{Ge}}{I_o \text{Si}} = \frac{\exp [0.718/0.06]}{\exp [0.435/0.03]} \cong 4 \times 10^3$$

44. Given that,

For $V_T = 400 \text{ mV}$

$I_D = 1 \text{ mA}$

$V_{gs} = 900 \text{ mV}$

For $V_{gs} = 1400 \text{ mV}$

$I_D = ?$

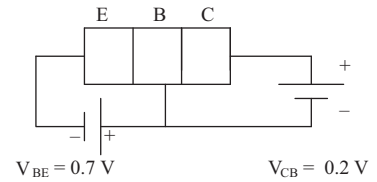
Using, $I_D = K (V_{gs} - V_T)^2$

$$\frac{1 \times 10^{-3}}{I_D} = \left(\frac{900 - 400}{1400 - 400} \right)^2$$

$$\frac{1 \times 10^{-3}}{I_D} = \frac{1}{4}$$

$I_D = 4 \text{ mA}$

45.



If, $V_{BE} = 0.7 \text{ V}$ -- Forward biased

$V_{CB} = 0.2 \text{ V}$ --- Reverse biased

Transistor operates in normal active mode

46. $V_T = 1V$, $I_D = 1 \text{ mA}$, $V_{GS} = 2V$

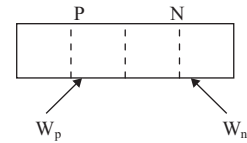
$V_T = 1$, $V_{GS} = 3 \text{ V}$, $I_D = ?$

$I_D = k (V_{GS} - V_T)^2$

$$\frac{I_{D2}}{I_{D1}} = \frac{(V_{GS2} - V_T)^2}{(V_{GS1} - V_T)^2} = \frac{(3-1)^2}{(2-1)^2}$$

$I_{D2} = [4/1] \times 1 = 4 \text{ mA}$

47. 0.25



$$N_a W_p = N_d W_n$$

$$= 4 N_a W_n$$

Or, $[W_p/W_n] = 4$

Or, $[W_n/W_p]$

$= 0.25$

Higher the doping level lesser the width of depletion layer.

48. Silicon sample having phosphorous 10^{16} group 5 donor, boron 2×10^6 group 3 acceptor, $N_a > N_d$ material is p type

$P = N_a - N_d = 10^{16}$

49. Donor concentration $N_D = 10^{19}/\text{cm}^3$

Excess electron concentration i.e.,

Δn hole concentration = $10^{15}/\text{cm}^3$

Generation rate of minority Carrier =

$\frac{\text{Excess hole concentration}}{\text{Hole life time}}$

$$= \frac{10^{15}}{10 \times 10^{-6}} = 10^{20} \text{ e. h pair/cm}^3/\text{s}$$

50. This diode behave as capacitor. Therefore voltage across the capacitor and current through the inductor does not change instantaneously.

$$I_R = \frac{10 \text{ V}}{100 \Omega} = 100 \text{ mA}$$

51. The ratio $[\sigma/\omega\epsilon]$ is a good measure of the conductivity of the material. Hence

$$\frac{\sigma_o}{\omega\epsilon} = \frac{10^6}{10 \times 10^9 \times 10 \times 8.85 \times 10^{-12}}$$

$$= 1.12 \times 10^6 \gg 1$$

Hence the material is a good conductor

52. Mobility $\mu = [V_d/E]$

drift velocity $V_d = 1/(20 \times 10^{-6})$

$$\mu = \frac{1}{20 \times 10^{-6}} \times \frac{1}{10} = 0.5 \times 10^4$$

$$= 5000 \text{ cm}^2/\text{volt-sec}$$

53. Electrons are promoted from the valence band to the conduction band by thermal energy. $F(E)$ is essentially 0 in the valence band and 1 throughout the conduction band. Fermi level is inside the conduction band: $P(E) = 1$

54. $np = n_i^2 \rightarrow$ mass action law

$$n = \frac{n_i^2}{P} = \frac{(1.5 \times 10^{10})^2}{2.25 \times 10^{15}} = \frac{2.25 \times 10^{20}}{2.25 \times 10^{15}}$$

$$= 10^5/\text{cm}^3$$

55. $C_i = \frac{C_o}{[1 + V_R/V_T]^n}$

where, $n = 1/2$ for abrupt junction

57. $np = n_i^2$

$$P = \frac{2.25 \times 10^{20}}{2.25 \times 10^{15}}$$

$$= 1.0 \times 10^5/\text{cm}^3 \text{ and}$$

$$n = 2.25 \times 10^{15}/\text{cm}^3$$

59. Let majority carrier be electron: $n = 5 \times 10^{20}$

Intrinsic carrier $n_i = 1.5 \times 10^{16}$

Now according to MASS-ACTION LAW

$$np = n_i^2 \quad ; \quad p = \frac{n_i^2}{n} = \frac{(1.5 \times 10^{16})^2}{5 \times 10^{20}}$$

$$= 4.50 \times 10^{11}/\text{m}^3$$

60. Conductivity $\sigma = ne\mu_n + pe\mu_p$

For N type $\sigma = ne\mu_n$

Resistivity $\rho = [1/ne\mu_n]$

Resistance of the bar $= [\rho\ell/A] = [\ell/\sigma \cdot A]$

$$[\ell/ne\mu_n \cdot A]$$

$$= \frac{10^{-3}}{(5 \times 10^{20} \times 1.6 \times 10^{-19} \times 0.13)}$$

$$\times 100 \times 10^{-6} \times 10^{-6}$$

$$= 10^6 \text{ ohm}$$

61. $\lambda = [C/f]$; $f = [C/\lambda]$

$$E = hf = hC/\lambda$$

$$= \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{5490 \times 10^{-10}} \text{ Jules}$$

$$= 3.62 \times 10^{-19} \text{ Joules.}$$

In eV, the energy Band Gap Energy = $[E/e]$

$$= \frac{3.62 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$= 2.26 \text{ eV}$$

62. Doping $\uparrow \Rightarrow$ width of depletion layer $\downarrow$

$$\therefore N_A X_p = N_D (X - X_p)$$

Where, X = Total depletion width

$$\text{Or, } 9 \times 10^{16} X_p = 1 \times 10^{16} (3 - X_p)$$

$$\text{Or, } 9 X_p = 3 - X_p$$

$$\text{Or, } 10 X_p = 3$$

$$X_p = [3/10] = 0.3 \mu\text{m}$$

63. Conductivity for N-type semiconductor is

$$\sigma_N = eN_D \mu_n$$

$$N_D = \frac{\sigma_N}{\mu_n e} = \frac{1}{0.5 \times 1.6 \times 10^{-19} \times 1250}$$

$$= 1 \times 10^{16}/\text{cm}^3$$

64. $C_j \propto [1/\sqrt{(V_{bi} + V_R)}]$

$$= \text{i.e., } \propto [1/\sqrt{V_j}]$$

$$[C_2/C_1] \propto \sqrt{(1/4)}$$

$$\Rightarrow C_2 = 0.5 pF$$

65. $E_{g(\text{ev})} = [hc/\lambda]$

$$E_{g(\text{ev})} = \frac{12400}{\lambda(A^\circ)} = \frac{12400}{0.8700 \times 10^{-6} \times 10^{-4}}$$

$$= 1.416 \text{ eV}$$

Second Method

$$E = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{0.87 \times 10^{-6}}$$

$$= 22.85 \times 10^{-20} \text{ Joules}$$

$$E = \frac{22.85 \times 10^{-20}}{1.6 \times 10^{-19}} \text{ eV} = 1.42 \text{ eV}$$

66. Diffusion current density

$$J_n = e \cdot D_n \cdot [dn/dx]$$

Where, $dx = 0.5 \mu\text{m} = 0.5 \times 100 \mu\text{cm}$

$$dn = 10^{14}/\text{cm}^3$$

$$D_n = 25 \text{ cm}^2/\text{s}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$J_n = e \cdot D_n \cdot [dn/dx]$$

$$= 1.6 \times 10^{-19} \times 25 \times \frac{10^{14}}{(0.5 \times 10^{-6}) \times 10^2}$$

$$= 1.6 \times 50 \times 10^{-1} = 8 \text{ A/m}^2$$

67. $E_g(\text{Si}) = 1.21 - 3.6 \times 10^{-4} T_{(290)} = 1.1 \text{ eV}$

$$E_g(\text{Ge}) = 0.785 - 2.23 \times 10^{-4} T_{(290)}$$

$$= 0.76 \text{ eV}$$

68. Reverse saturation current becomes doubles for every 10 degree, rise in temperature i.e.,

$$I_o(T_i) = I_{oT} \times 2^{\frac{(T-T_i)}{10}}$$

$$I_s = 10 \Rightarrow \text{A at } 20^\circ \text{C}$$

$$I_s = 20 \Rightarrow \text{A at } 30^\circ \text{C}$$

$$I_s = 40 \Rightarrow \text{A at } 40^\circ \text{C}$$

69. Boron group – III element

phosphorous group – V element

Conductivity is proportional to doping concentration

$$N_A = 10^{18}, N_B = 10^{18},$$

$$[\mu_A/\mu_B] = [1/3]$$

$$\sigma = n q \mu \text{ Where,}$$

$n \rightarrow$ Carrier concentration

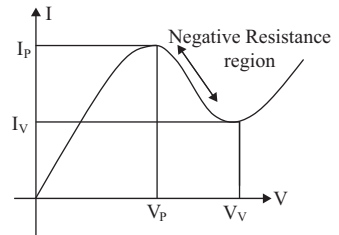
$$\frac{\sigma_A}{\sigma_B} = \frac{\mu_A}{\mu_B} = \frac{1}{3}$$

70. $C = \frac{\epsilon A}{d} = \frac{\epsilon_0 \epsilon_r A}{d}$

$$[C/A] = \frac{\epsilon_0 \epsilon_r}{d} = \frac{11.7 \times 8.85 \times 10^{-12}}{10 \times 10^{-6}}$$

$$[C/A] = 10.35 \mu\text{F}$$

71. The tunnel diode has characteristic



72. $\left(\frac{\mu_h}{\mu_e} = 0.4 \right)$

$$\frac{\sigma_{N\text{-type}}}{\sigma_{\text{intrinsic}}} = \frac{n_e \mu_e}{n_i \mu_e + n_i \mu_h}$$

$$= \frac{n_e \mu_n}{n_i (\mu_p + \mu_n)}$$

$$= \frac{n_e \mu_n}{n_i \left(1 + \frac{\mu_p}{\mu_n} \right)}$$

$$= \frac{4.2 \times 10^8}{1.5 \times 10^4 \times 1.4} = 20,000$$

73. Intrinsic concentrations $= n_i/\text{cm}^3$

Acceptor (Hole) concentrations $= N_A/\text{cm}^3$ i.e.,

$$\Rightarrow P \approx N_A$$

Electron concentrations $n = ?$

According to **mass action law**, $n_i^2 = n \cdot p$

$$\therefore \text{Electron concentrations } n = \frac{n_i^2}{P} = \frac{n_i^2}{N_A}$$

74. P-n junction built in volt = 0.8 V for applied 1.2 V reverse bias, width = 2 μm

Diode voltage = $V_a + V_b$

Where, V_a = applied volt

V_b = built in volt

Also $w \propto \sqrt{V_{\text{diode}}}$

$$\therefore \frac{w_1}{w_2} = \sqrt{\frac{V_1}{V_2}}$$

$$w_1 = 2 \mu\text{m}, w_2 = ?$$

$$V_1 = 1.2 + .8 = 2V$$

$$V_2 = 7.2 + .8 = 8V$$

$$\therefore \frac{2 \times 10^{-6}}{w_2} = \sqrt{\frac{2}{8}}$$

$$\therefore w_2 = 4 \mu\text{m}$$

75. DC current gain $\beta = 50$

Emitter injection efficiency = 0.995

base transportation factor = ?

$$\Rightarrow \text{Emitter efficiency} = \frac{I_{PE}}{I_{ETOT}}$$

$$\text{Base transportation factor, } B_T = \frac{I_{PC}}{I_{PE}}$$

α = Emitter efficiency $\times$ Base transportation factor

$$\therefore B_T = \frac{\alpha}{0.995} = \frac{\beta}{1 + \beta} \times \frac{1}{0.995}$$

$$= \frac{50}{51} \times \frac{1}{0.995} = 0.985$$

76. V_T is independent of circuit parameter, it depends on fabrication process and material used.

77. Conductivity $\sigma = n e \mu_n + p e \mu_p$

For N type $\sigma = n e \mu_n$

Resistivity $\rho = [1/n e \mu_n]$

Resistance of the bar = $[\rho \ell / A] = [\ell / \sigma \cdot A]$
 $[\ell / n e \mu_n \cdot A]$

$$= \frac{10^{-3}}{(5 \times 10^{20} \times 1.6 \times 10^{-19} \times 0.13)}$$

$$\times 100 \times 10^{-6} \times 10^{-6}$$

$$= 10^6 \text{ ohm}$$

78. $\lambda = [C/f]$; $f = [C/\lambda]$
 $E = hf = h \cdot C/\lambda$

$$= \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{5490 \times 10^{-10}} \text{ Jules}$$

$$= 3.62 \times 10^{-19} \text{ Joules.}$$

In eV, the energy Band Gap Energy = $[E/e]$

$$= \frac{3.62 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$= 2.26 \text{ eV}$$

79. In n-well CMOS fabrication, following are the steps:

1. n-well implant
2. Source/drain diffusion
3. Metalization
4. Passivation

$$\begin{aligned} 80. J_n &= +q D_n [dn/dx] \cong \\ &\cong [1.6 \times 10^{-19} \times 35 \times 10^{-4}] \times \\ &\quad \frac{(6 \times 10^{16} - 10^{17})}{2 \times 10^{-6}} \end{aligned}$$

$$= 1.6 \times 10^{-19} \times 35 \times 10^{-4} \times [4/2] \times 10^{22}$$

$$= +1120 \text{ A/cm}^2$$

81. $V_T = 300 \text{ K}$

$$I = 1 \text{ mA}$$

$$\text{For Si, } I = I_o \text{Si} [\exp V/nV_T - 1];$$

$$n = 2 \text{ for Si}$$

$$1 \text{ mA} = I_o \text{Si} [\exp \frac{0.718}{2 \times 0.03} - 1]$$

$$\text{For, Ge } I = I_o \text{Ge} [\exp \frac{0.1435}{1 \times 0.03} - 1]$$

$$\frac{I_o \text{Ge}}{I_o \text{Si}} = I_o \text{Ge} \exp \left(\frac{0.1435}{1 \times 0.03} - 1 \right)$$

$$= I_o \text{Si} \left(\exp \frac{0.718}{1 \times 0.03} - 1 \right)$$

$$\frac{I_o \text{Ge}}{I_o \text{Si}} = \frac{\exp [0.718/0.06]}{\exp [0.435/0.03]} \cong 4 \times 10^3$$

LEVEL 3

1. Use relation of hybrid $-\pi$ model for high frequency

$$\text{Input resistance, } R_{IN} = \frac{h_{fe}}{g_m} = \frac{\beta}{g_m}$$

$$= \frac{50}{10\text{ms}} = 5 \text{ k}\Omega$$

Since it is a common emitter with by pass R_{E-}

Net input impedance

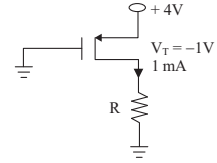
$$= R_1 \parallel R_2 \parallel R_{in}$$

$$= 10\text{k}\Omega \parallel 10\text{k}\Omega \parallel 5 \text{ k}\Omega$$

$$= 5\text{k}\Omega \parallel 5\text{k}\Omega$$

$$= 2.5 \text{ k}\Omega$$

2.



$$V_{GS} = -4V; V_{DS} = -4V; V_T = -1V$$

$$|V_{GS} - V_T| > |I_d R + V_{DS}|$$

$$\text{i.e., } |-4 + 1| > |R \times 10^{-3} - 4|$$

$$\Rightarrow 3 > (-R \times 10^{-3} + 4)$$

$$\Rightarrow R > 1000 \Omega$$

$$\text{Hence } R = 1200 \Omega.$$

$$3. \frac{V_o(s)}{V_i(s)} = \frac{s / R_2 C_1}{s^2 + \frac{C_1 + C_2}{R_1 C_1 C_2} s + \frac{1}{R_1 R_2 C_1 C_2}}$$

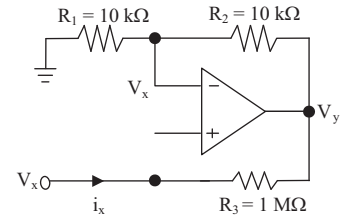
$$A_v(s) = \frac{(\omega_o / Q) A_o s}{s^2 + (\omega_o / Q) s + \omega_o^2}$$

$$\text{comparing we have, } \frac{\omega_o}{Q} = \frac{C_1 + C_2}{R_1 C_1 C_2}$$

$$\text{or } \omega_o = Q \cdot \left(\frac{C_1 + C_2}{R_1 C_1 C_2} \right)$$

$$= 1 \cdot \frac{10^{-9} \times 2}{200 \times 10^3 \times 10^{-18}} = 10^4 \text{ rad/sec.}$$

4.



Using KCL at inverting terminal, we have

$$\frac{v_x - v_y}{R_2} + \frac{v_x - 0}{R_1} = 0$$

$$\text{or } \frac{v_x}{v_y} = \frac{R_1}{R_1 + R_2} \quad (1)$$

Using same at non-inverting terminal, we get

$$i_x = \frac{v_x - v_y}{R_3} = \frac{v_x - v_x \left(\frac{R_1 + R_2}{R_1} \right)}{R_3}$$

$$\text{or } i_x = -\frac{v_x R_2}{R_1 R_3}$$

$$\text{or } R_{IN} = \frac{v_x}{i_x} = -\frac{R_1 R_3}{R_2}$$

$$= -\frac{10^4 \times 10^6}{10 \times 10^3} = -1000 \text{ k}\Omega = -1 \text{ M}\Omega$$

5. Average ON-state loss

$$= \frac{1}{(2\pi/\omega)} \int_0^{\pi/\omega} i^2 R dt$$

$$= \frac{1}{2\pi} \cdot 10^2 \cdot 0.15 \cdot \pi = 7.5 \text{ Watts.}$$

6. Average current through the diode

$$= \frac{\alpha V_s}{R} = \frac{0.8 \times 100}{10} = 8 \text{ A}$$

7. MOSFET is n-channel. Gate voltage is so connected that MOSFET will be in Enhance mode and so conductivity of the channel will be increase very much, and effectively P terminals acts as short circuited.

8. Inside metal electric field
- $|E| = 0$

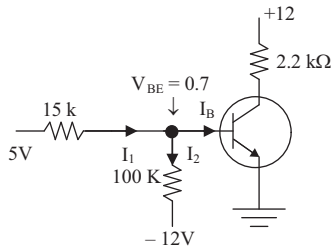
In dielectric electric field $|E| = \text{constant.}$

In semiconductor, electric field $|E|$ follow. The charge density. As we move away, from the junction charge density decreasing due to diffusion of electrons and holes.

- 9.
- $D_1 = \text{on (Forward biased)}$

$D_2 = \text{Off (Reverse biased)}$ There is more negative across it than positive voltage

10.



$$V_{BE} = 0.7 \text{ V}$$

$$I_1 = \frac{5 - 0.7}{15\text{k}} = \frac{4.3}{15\text{k}} = 0.286 \text{ mA}$$

$$I_1 = 286.67 \mu\text{A}$$

$$I_2 = \frac{0.7 + 12}{100\text{k}} = \frac{12.7}{100\text{k}} = 0.127 \text{ mA}$$

$$I_2 = 127 \mu\text{A}$$

$$I_B = I_1 - I_2 = 0.286 - 0.127 = 0.159 \text{ mA}$$

$$I_B = 159.67 \mu\text{A}$$

$$I_c = \beta I_B + (\beta + 1) I_{CBO}$$

$$= 30 \times 159.7 \mu\text{A} + 31 \times 20 \times 10^{-9}$$

$$I_c = 4.79 \text{ mA}$$

$$V_{CE} = 12 - 2.2 \times 4.79 = 1.462 \text{ V}$$

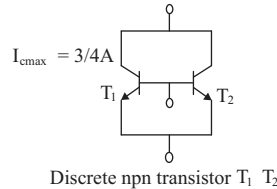
$$V_{CB} = V_{CE} - V_{BE} = 1.462 - 0.7 = 0.762$$

V_{CB} is positive so transistor is operating in the active region

11. For saturation region, there is least change in output irrespective of any change in input.

Now since base resistance R_b is very high as compared to collector and emitter resistance, the output of this transistor configuration is unaffected by any change in input.

12.



Total current I_A

When switched on T_1 draws 0.55 A and T_2 draws 0.45 A T_1 will get more heated and current increases

Ultimately $I_1 = 1 \text{ A}$ and $I_2 = 0$

$$13. I = I_o [e^{V/V_T} - 1]$$

$$= 10^{-13} [e^{0.7/26 \times 10^{-3}} - 1]$$

$$= 10^{-13} [e^{0.026 \times 10^3} - 1]$$

$$= 10^{-13} [e^{26} - 1]$$

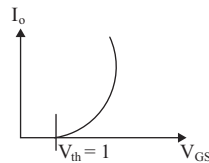
$$= 10^{-13} [1.95 \times 10^{11} - 1]$$

$$= 1.95 \times 10^{-2}$$

$$= 1.95 \times 10^{-3}$$

$$= 20 \text{ mA}$$

14.



$$V_{DS} = 5 - 1 = 4$$

$$V_{GS} = 3 - 1 = 2$$

$$V_{GS} - V_{th} = 2 - 1 = 1$$

In present case: $V_{DS} > V_{GS}$ i.e., $4 > 1$

So device is in saturation

15. For high Gate input (2.5 V) only NMOS will conduct and PMOS switch off

$$\therefore I_d = k_n (V_{gs} - V_{THn})^2$$

$$= 40 \times 10^{-6} (2.5 - 1)^2$$

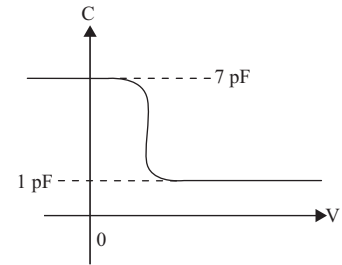
$$= 40 \times 10^{-6} \times 2.25$$

$$= 90 \mu\text{A}$$

16. For diode forward biased and
- $V_R = 5$
- .

At $t = 0$ diode abruptly changes to reverse biased and current across resistor must be 0, but in storage time $0 < t < t_s$ diode retain its resistance of forward biased. Thus for $0 < t < t_s$ it will be on and $V_R = -5 \text{ V}$

17.



$$C = \frac{\epsilon_o \epsilon_r A}{w}$$

$$w = \frac{3.5 \times 10^{-13} \times 10^{-4}}{0.7 \times 10^{-12}}$$

$$= 5 \times 10^{-5} \text{ cm}$$

$$= 50 \times 10^{-9} \text{ m} = 50 \text{ nm}$$

CHAPTER 3

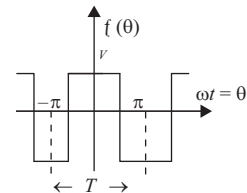
LEVEL 1

$$1. \int_0^t u(t) dt = t$$

$$\int_0^t t dt = \left(\frac{t^2}{2} \right) \text{ This is parabola}$$

$$4. = \int \phi \sin(\omega t + \phi) d\phi.$$

5. Fourier series for the given wave form



$$f(t) = \frac{4v}{\pi} \left(\cos \omega t - \frac{1}{3} \cos 3\omega t + \dots \right)$$

In present case, the peak value of $f(t)$ is v . Its Fourier series amplitude exceeds the peak value.

7. Laplace transform of
- $x(t)$
- ,

$$X(s) = \int x(t) e^{-st} dt$$

$$= \int_{-\infty}^{\infty} x(t) e^{-(\sigma + j\omega)t} dt$$

S.14 ■ Solutions

For $\sigma = 0$,

$$X(s) = X(j\omega) = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt$$

which corresponds to the Fourier transform of $x(t)$.

8. Fourier transfer represent continuous pulse function for stationary power which gives energy per Hz

$$10. f(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} a_k \cos k\omega_0 t + \sum_{k=1}^{\infty} b_k \sin k\omega_0 t$$

Thus, $f(t)$ is represented by infinite sum of sinusoids having condition that these sinusoids must have frequency f_0 and its harmonics $2f_0, f_0, \dots$

11. Integrate rectangular pulse $\rightarrow$ triangular wave

$$f_o(t) = f_i(t) * f_i(t)$$

$$f(t-T) * f_i(t-T) = f(t-2T)$$

12. If output depends upon present and/or past, the system is causal and does not depend on future input.

13. Zero-state response means the response when the initial conditions are zero.

$$f(t) = u(t) + u(t-1) - 2u(t-2)$$

$$F(s) = \frac{1}{s} + \frac{e^{-s}}{s} - \frac{2e^{-2s}}{s}$$

14. Non-causal and time-variant.

$$(1) y(t) = x(t^2)$$

$$\text{for } t = 4 \rightarrow y(-1) = x(1)$$

Hence non causal

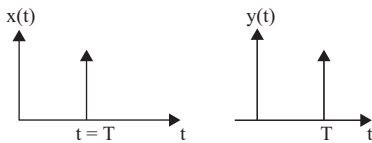
$$(2) a y_1(t) + b y_2(t) = a x_1(t^2) + b x_2(t^2)$$

$\therefore$ Linear

$$(3) y(t-t_o) = x(t-t_o)^2$$

$\therefore$ Time varying.

- 15.



Causality sequence is defined as

$$x(t) = 0 \text{ for } t < 0$$

$$h(n) = 0 \text{ for } n < 0$$

Since value of the signal start at T and its response is zero for all interval of time below T . Hence it is a causal system.

16. $s(t) = \cos 2t + \cos 3t + \cos 5t$

Period = 2π

$$s(t) = e^{j8\pi t}$$

$$s(t+T) = e^{j8\pi(t+T)} = e^{j8\pi t} e^{j8\pi T}$$

$$T = \frac{2\pi}{8\pi} = \frac{1}{4} \text{ period}$$

$$s(t) = e^{-7t} \sin 10\pi t$$

$$s(t+T) = e^{-7(t+T)} \sin 10\pi(t+T)$$

$$= e^{-7t} e^{-7T} \sin 10\pi t$$

Exponentially decreasing function value becomes zero after some time, hence it is non periodic

$$s(t) = \cos 2t \cdot \cos 4t$$

$$= \frac{1}{2} [\cos 6t + \cos 2t]$$

$$s(t+T) = \cos(2t+2T) \cos(4t+4T)$$

$T = \pi$ Periodic

17. If $g(t)$ is real and odd then $G(f)$ will be imaginary and odd.

Here, $g(t)$ is l odd symmetric

$g(t)$ odd $\Rightarrow G(f)$ imaginary

$g(t)$ even $\Rightarrow G(f)$ real

18. LT $[f(t)] = F(s)$

From final value theorem,

$$\lim_{t \rightarrow \infty} f(t) = \lim_{s \rightarrow 0} sF(s)$$

$$= \lim_{s \rightarrow 0} sF(s) = \frac{K}{(s+1)(s^2+4)} = \frac{K}{4}$$

$$19. x(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos n\omega_s t + \sum_{n=1}^{\infty} b_n \sin n\omega_s t$$

If $x(t)$ is odd function then it will contain sine term only i.e., $\sin \omega_s t$ is odd function

$$20. x(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos n\omega_s t + \sum_{n=1}^{\infty} b_n \sin n\omega_s t$$

If $x(t)$ is even function then it will not contain sine term $\sin \omega_s t$ is odd function.

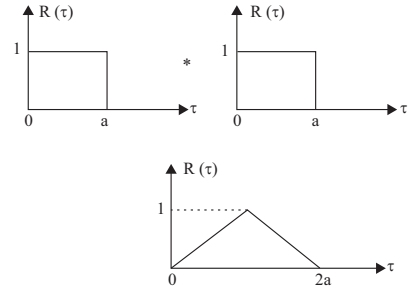
21. The Fourier transform of a real valued time signal had conjugate symmetry.

22. For an energy signal the auto correlation function has even symmetry i.e., $R(\tau) = R(-\tau)$

23. Power spectral density (frequency domain) and auto correlation function (time domain) are Fourier transform pair.

Since power spectral density is $\left[\frac{\sin(f)}{f} \right]^2$.

Which mean that it is a convolution of two rectangular auto correlation functions. i.e.,



26. $L[f(t)] = F(s)$ then $L[f(t-T)]$

is equal to $e^{-sT} F(s)$.

Apply time shifting property of Laplace transform.

27. If $x(t)$ is real and odd function of t and then $X(\omega)$ is imaginary and odd function of ω .

$$28. \sum_{K=-\infty}^{+\infty} h(K) =$$

$$\sum_{K=-3}^{\infty} u(K+3) + \sum_{K=-2}^{\infty} u(K-2) - 2 \sum_{K=7}^{\infty} u(K-7)$$

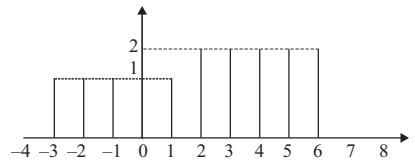
$$= \sum_{K=-3}^6 1 + \sum_{K=2}^6 1 = 10 + 5 = 15 < \infty$$

Therefore, the system is stable

Also, the three system described by $h[n]$ is non-causal because, the response depends upon the future value of the input signal, namely $u[n+3]$.

Second Method

$$h(n) = u(n+3) + u(n-2) - 2u(n-7)$$



$$\sum_{n=-\infty}^{\infty} h(n) = 1 + 1 + 1 + 1 + 1 + 2 + 2 + 2 + 2 + 2 = 15$$

We can see that $\sum_{n=-\infty}^{\infty} h(n)$ is finite hence system is stable.

Since $h(n)$ depends on $u(n+3)$ i.e., future values, so it is not a causal system.

29. Fourier transform of a conjugate symmetric function is always real

$$30. s(t) = 8 \cos [20\pi t - \{\pi/2\}]$$

$$+ 4 \sin (15\pi t)$$

$$= 8 \sin (20\pi t) + 4 \sin (15\pi t)$$

$$\text{Power in the signal} = [8/\sqrt{2}]^2 + [4/\sqrt{2}]^2$$

$$= [64/2] + [16/2]$$

$$= [80/2] = 40$$

31. $c(t) = 1 - e^{-2t}$; $r(t) = u(t)$; $R(s) = [1/5]$

$$C(s) = \frac{1}{s} - \frac{1}{s+2} = \frac{2}{s(s+2)}$$

$$H(s) = \frac{C(s)}{R(s)} = \frac{2}{(s+2)}$$

32. For any signal $g(t)$ its Hilbert transform is

$$\hat{g}(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{g(\tau)}{(t-\tau)} d\tau$$

System is non-linear because for

$$t=0 \quad \hat{g}(t) \neq 0$$

33. $f(t) \rightarrow F(\omega)$, $f(-t) \rightarrow F^*(\omega)$

F^* is conjugate of $F(\omega)$

The Fourier transform pair

$$f(t) - f(-t) = F(\omega) - F^*(\omega)$$

it must be imaginary

Then, $F^*(\omega)$ as difference of $F(\omega)$ and $F^*(\omega)$

34. Since, pole zero plot of all pass filter is symmetrical about $j\omega$ axis, hence only possible answers is

$$\frac{1-s\tau}{1+s\tau}$$

35. $i = A \sin \omega t$; $\omega = 2\pi/T$

$$i(t) = 10 + 20 \sin t$$

$$\begin{aligned} I_{rms} &= \left[\frac{1}{2\pi} \int_0^{2\pi} (10 + 20 \sin t)^2 dt \right]^{1/2} \\ &= \left[\frac{1}{2\pi} \int_0^{2\pi} (100 + 400 \sin^2 t + 400 \sin t) dt \right]^{1/2} \\ &= \left[\frac{1}{2\pi} \int_0^{2\pi} (100 + 200(1 - \cos 2t) + 400 \sin t) dt \right]^{1/2} \\ &= \left[\frac{1}{2\pi} \int_0^{2\pi} (300 - 200 \cos 2t + 400 \sin t) dt \right]^{1/2} \\ &= \left[\frac{1}{2\pi} \int_0^{2\pi} 300 dt \right]^{1/2} = \sqrt{300} = 17.3 \text{ A} \end{aligned}$$

36. Apply final value theorem

$$x(\infty) = \lim_{t \rightarrow \infty} f(t) = \lim_{s \rightarrow 0} sF(s)$$

$$= \lim_{s \rightarrow 0} \frac{s(5s^2 + 23s + 6)}{(s^2 + 2s + 2)s} = 3$$

38. This is care of

Half wave and even symmetry

$a_o =$ Find out.

$$a_n = 0 \quad n \text{ even}$$

$$a_n = \frac{8}{T} \int_0^{T/4} f(t) \cos(n\omega_o t) dt \quad n \text{ odd}$$

$$b_n = 0 \quad \text{all } n$$

39. $y(t) = e^{-|x(t)|}$

Therefore, e^{-x} is always convergent even when x is not bounded

Therefore e^{-x} is bounded even though x^2 is not bounded.

40. The running integrator $\int_{-\infty}^t x(t') dt' = 0$ for every causal system.

As causal system have no memory and initial values, is zero the output is followed by input so, $y(t)$ will always be bounded if this function is causal bounded system.

LEVEL 2

1. $y(t) = x(t) * \int_{-\alpha}^{\alpha} h(\tau) x(t-\tau) d\tau$

$$h(t) = \frac{da(t)}{dt}$$

2. $y[n] = x[n-2]$

$$\therefore H(z) = z^{-2}$$

$$H(Z) = H_1(Z) \cdot H_2(Z)$$

$$\Rightarrow H_2(Z) = \frac{H(Z)}{H_1(Z)}$$

3. $S_p(\omega) = |H(\omega)|^2 S_g(\omega) = \frac{A}{(\omega^2 + 1)}$

4. $I = \sqrt{c_0^2 + \frac{c_1^2}{2} + \frac{c_2^2}{2}}$

$$\sqrt{2^2 + \frac{(6\sqrt{2})^2}{2} + \frac{(\sqrt{48})^2}{2}} = 8A$$

5. $E_g = \int_{-\infty}^{\infty} \frac{V^2(t)}{R} dt = \int_{-\infty}^{\infty} V^2(t) dt$

$$= \frac{1}{2\pi} \int_{-\infty}^{\infty} |V(\omega)|^2 d\omega$$

$$= \frac{1}{2\pi} \int_{-1}^1 |e^{-2j\omega d}| d\omega = \frac{1}{2\pi} \int_{-1}^1 d\omega$$

$$= \frac{1}{\pi} \text{ joule.}$$

6. $u(t) \rightarrow (1/s)$

$$t^2 \rightarrow (2/s^3); e^{-2t} \rightarrow [1/(s+2)]$$

$$t^2 e^{-2t} \rightarrow [2/(s+2)^3]$$

$$H(s) = \frac{\text{LT of output}}{\text{LT of input}} = [2s/(s+2)^3]$$

7. Two second order systems are connected in cascaded there resulted transform function is multiplication of above two. Therefore final transform function will be of the order of four.

$$s_3(t) = s_1(t) * s_2(t)$$

$$\text{i.e., } S_3(s) = S_1(s) \cdot S_2(s)$$

8. $x_3(t) = \alpha x_1^2(t) + \alpha x(t)$

$$+ \beta [x_1^2(\tau) + x(t)]$$

$$y_3(t) = \alpha [x_1(t) + x_2(t)]^2 + \beta$$

$$[x_1(t) + x_2(t)]$$

$$-x_3(t) + y_3(t)$$

non-linear.

9. A system is causal if the output any time depends only on values of the input at the present time and in the pass.

Thus, only (b) satisfies it.

10. Given system is

$$H(s) = \frac{s+1}{(s+1)^2 + 1}$$

$$X(s) = \frac{1}{s+1}$$

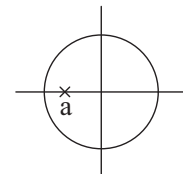
Therefore,

$$Y(s) = H(s) X(s) = \frac{1}{(s+1)^2 + 1}$$

$$\text{Therefore, } y(t) = e^{-t} \sin t u(t)$$

$$\text{as } e^{-bt} \sin at \rightarrow \frac{a}{(s+b)^2 + a^2}$$

11.

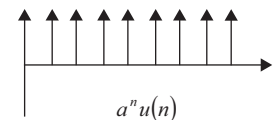


Pole-Zero Plot

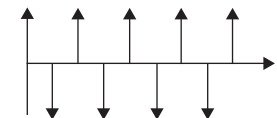
$$x(t) = a^n u[n]; X(z) = \frac{1}{1-z^{-1}}$$

Pole $z = a$

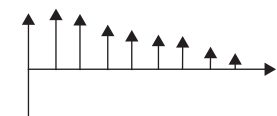
(1) If pole lie on +1 then signal is



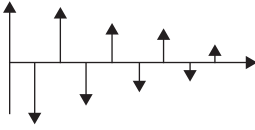
(2) if $a = -1$



(3) $a \in (0, 1)$



(4) if $a \in (0, -1)$

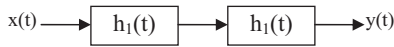


$$12. \quad y(t) + \int_0^{\infty} y(\tau) x(t-\tau) d\tau = \delta(t) + x(t)$$

Therefore $y(t) = \delta(t)$.

$$13. \quad h_1(t) = \delta(t - 0.5)$$

$$H_1(s) = e^{-0.5s}$$



Therefore for cascaded system

$$h(t) = h_1(t) * h_2(t)$$

$$\text{Or } H(s) = H_1(s) \cdot H_1(s) = e^{-0.5s} \cdot e^{-0.5s} = e^{-s}$$

Therefore $h(t) = \delta(t - 1)$.

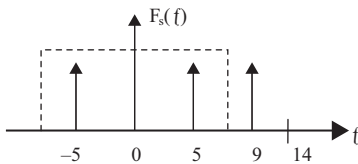
$$14. \quad f(t - T) = F(s) e^{-sT}$$

as here e^{-sT} term is present. Minimum three delay element required.

$$15. \quad x(t) = 6 \cos 10\pi t$$

$$\omega = 2\pi f$$

$$f_m = \frac{\omega}{2\pi} = \frac{10\pi}{2\pi} = 5 \text{ Hz}$$



$$f = nf_s + f_m \text{ where } n = 0, 1, 2$$

in present case $f_s = 14 \text{ Hz}$

$$f = \pm 5, 9, 19$$

Therefore $5 < f_c < 9$

$$16. \quad y'' + 3y' + 2y = u(t)$$

Let, $x_1 = y$

$$x_2 = y' = x_1'$$

$$x_2' = y''$$

$$= -3y' - 2y + u(t)$$

$$= -2x_1 - 3x_2 + u(t)$$

$$\text{Therefore, } \begin{bmatrix} x_1' \\ x_2' \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u$$

$$18. \quad f(t) = A e^{-a|t|}; \text{ for all } t$$

It is double side exponential signal.

$$\text{for } +ve \ t \ |t| \rightarrow +t; \ f(t) = A e^{-a \ t}$$

$$\text{-ve } t \ |t| \rightarrow -t; \ f(t) = A e^{+a \ t}$$

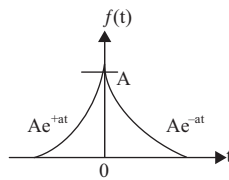
$$f(t) = A e^{-a \ t}; \ t > 0$$

$$= A e^{+a \ t}; \ t < 0$$

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t} dt$$

$$= \int_{-\infty}^0 A e^{+a \ t} e^{-j\omega t} dt + \int_0^{\infty} A e^{-a \ t} e^{-j\omega t} dt$$

$$= \int_{-\infty}^0 A e^{(a-j\omega)t} dt + \int_0^{\infty} A e^{-(a+j\omega)t} dt$$



$$= A \left[\frac{e^{(a-j\omega)t}}{a-j\omega} \right]_{-\infty}^0 + A \left[\frac{e^{-(a+j\omega)t}}{-(a+j\omega)} \right]_0^{\infty}$$

$$= \frac{A}{a-j\omega} [1-0] + \frac{A}{-(a+j\omega)} [0-1]$$

$$= \frac{A}{a-j\omega} + \frac{A}{(a+j\omega)}$$

$$= A \frac{2a}{a^2 + \omega^2}$$

$$F(\omega) = \frac{2a \cdot A}{a^2 + \omega^2}$$

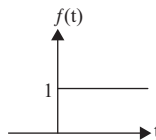
In present case $A = 1$ and $a = b$

Therefore the answer is

$$F(\omega) = \frac{2b}{b^2 + \omega^2}$$

$$19. \quad u(t) = 0; \ t < 0$$

$$= 1; \ t > 0$$



Consider the following function

$$2 \ u(t) = 1 + \text{Sgn}(t)$$

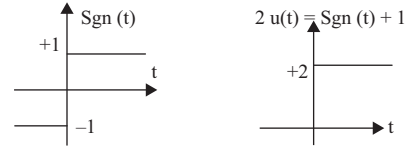
$$u(t) = 1/2 [1 + \text{Sgn}(t)]; \ t > 0$$

$$= 0; \ t < 0$$

$$F T [u(t)] = [1/2] F T [\text{sgn}(t) + 1]$$

$$= [1/2] [(2/j\omega) + 2\pi \delta(\omega)]$$

$$F T [u(t)] = (1/j\omega) + \pi \delta(\omega)$$



step function with height 2

20. $x(t)$ is periodic with $T = 2\pi$ and hence it is a power signal

$$P = \frac{1}{T} \int_0^T [x(t)]^2 dt$$

$$= \frac{1}{2\pi} \int_0^{2\pi} A^2 \cos^2(\omega_0 t + \phi) dt$$

$$= \frac{A^2}{2}$$

24. Case 1:

$$\text{Input} \rightarrow u(n) \rightarrow \frac{1}{1-z^{-1}} \rightarrow X_1(z)$$

$$\text{Output} \rightarrow \delta(n) \rightarrow 1 \rightarrow y_1(z)$$

$$H(z) = \frac{Y_1(z)}{X_1(z)} = \frac{1}{1/[1-z^{-1}]} = [1-z^{-1}]$$

Case 2:

$$\text{Input} \rightarrow nu(n) \rightarrow \frac{1}{(1-z^{-1})^2} \rightarrow X_2(z)$$

$$Y(s) = H(z) X_2(z)$$

$$= \frac{(1-z^{-1})}{(1-z^{-1})} = \frac{1}{(1-z^{-1})} \rightarrow u(n)$$

$$25. \quad X(z) = \frac{z+z^{-3}}{z+z^{-1}} = \frac{1+z^{-4}}{1+z^{-2}}$$

$$= \frac{1}{1+z^{-2}} (1+z^{-4})$$

$$= (1-z^{-2} + z^{-4} - z^{-6} + \dots)(1+z^{-4}) t$$

$$26. \quad H(Z) = \frac{Y(Z)}{X(Z)}$$

$$= C(ZI - A)^{-1} B + D$$

$$27. \quad z = x - y$$

Mean and variance are added up

$$z_0 = x_0 - y_0; \quad \sigma_z^2 = \sigma_x^2 - \sigma_y^2.$$

$$29. \quad f(at) \rightarrow \frac{1}{|a|} F(f/a)$$

$$f(at^2) \rightarrow \frac{1}{\sqrt{|a|}} F(f^2/a^2)$$

Put $a = \alpha/\pi$, we get the solution.

$$30. V_{av} = \frac{1}{\pi} \int_0^{\pi} v(t) d(\omega t) = \frac{V_m}{\pi}.$$

$$31. u(t) = \int_0^{\infty} \delta(t) dt$$

$$\delta(t) = \frac{du(t)}{dt}$$

Similarly, difference is the inverse of summation.

$$x[n] = u[n] - y[n-1].$$

$$33. h[n] = \delta[n+2] - \delta[n-2]$$

$$H(z) = z^2 - z^{-2}$$

$$Y(z) = (z^2 - z^{-2})X(z)$$

$$z^{-2} Y(z) = X(z) - z^{-4} X(z)$$

$$y[n-2] = x[n] - x[n-4].$$

$$34. F(s) \cdot G(s) \leftrightarrow f(t) * g(t).$$

35. Integrate rectangular pulse $\rightarrow$ triangular wave

$$f_o(t) = f_i(t) * f_i(t)$$

$$f(t-t) * f_i(t-T) = f(t-2T).$$

36. An equation of the form

$$\sum_{k=0}^N a_k y[n-k] = \sum_{k=0}^M b_k x[n-k]$$

is called a **recursive equation**

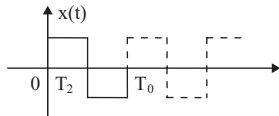
when $N = 0$, $y[n]$ is an explicit function of the present and previous values of the input and it is then called a non-recursive equation.

37. Characteristic equation

$$sI - A = \begin{bmatrix} s & -\alpha \\ -\alpha & s \end{bmatrix}$$

$$\text{or, } s^2 - \alpha^2 = 0 \quad \text{or, } s = \pm \alpha.$$

39.



Odd Symmetry

dc value $a_0 = 0$

$$b_n = 0$$

$$a_n = \frac{4}{T_0} \int_0^{T_0/2} x(t) \sin n \omega_0 t dt$$

$$= \frac{4}{T_0}$$

$$\left[\int_0^{T_0/2} A \sin n \omega_0 t dt + \int_{T_0/2}^{T_0} (-A) \sin n \omega_0 t dt \right]$$

$$= \frac{2A}{n\pi} (1 - \cos n\pi).$$

$$40. \frac{1}{s} \leftrightarrow u(t)$$

$$\frac{e^{-as}}{s} \leftrightarrow u(t-a)$$

$$41. x_1(t) e^{k_1 t} \leftrightarrow \frac{1}{s-k_1}$$

$$x_2(t) e^{k_2 t} \leftrightarrow \frac{1}{s-k_2}$$

$$= x_1(t) * x_2(t) \leftrightarrow \frac{1}{(s-k_1)(s+k_2)}$$

$$= \frac{1}{k_1 + k_2} \left[\frac{1}{(s-k_1)} - \frac{1}{(s+k_2)} \right]$$

Therefore

$$x_1(t) * x_2(t) = \frac{1}{k_1 + k_2} [e^{k_1 t} - e^{-k_2 t}] u(t)$$

42. For periodic signal $x(t \pm T_o) = x(t)$.

$$43. y[n] = x[n] * h[n]$$

$$= \sum_{k=-\infty}^{\infty} h[k] x[n-k]$$

$$= \sum_{k=-\infty}^{\infty} \left(\frac{1}{2} \right)^k u[k] \cdot [3 + \cos(n\pi + \pi/3 - k\pi)]$$

$$3 \sum_{k=-\infty}^{\infty} \left(\frac{1}{2} \right)^k \cdot u[k] + \sum_{k=-\infty}^{\infty} \left(\frac{1}{2} \right)^k \cos(n\pi + \pi/3 - k\pi) u[k]$$

$$= \sum_{k=0}^{\infty} 3 \left(\frac{1}{2} \right)^k + \sum_{k=0}^{\infty} \dots$$

$$= 3 \times \frac{1}{1 - \frac{1}{2} + \dots}$$

$$= 6 + \sum_{k=0}^{\infty} \left(\frac{1}{2} \right)^k \cos(n\pi + \pi/3 - k\pi)$$

$$= 6 + \frac{2}{3} \cos\left(n\pi + \frac{\pi}{3}\right).$$

44. For system to be causal,

$$h[n] = 0 \text{ for } n < 0$$

Therefore, system is non-causal as $h[n] \neq 0$ for $n = -1, -2$,

For system to be memory less,

$$h[n] = k\delta[n]$$

Therefore, system has memory.

45. Given Polynomial is

$$F(z) = 4z^3 - 8z^2 - z + 2$$

$$= 4z^2(z-2) - 1(z-2) = (4z^2 - 1)(z-2)$$

$$z = \pm \frac{1}{2}, 2$$

Therefore roots are at $2, +\frac{1}{2}, -\frac{1}{2}$

Therefore Number of roots lying outside the unit circle is 1.

46. Method 1

Cross-Correlation Table

	1	3	1	2
3	3	9	3	6
1	1	3	1	2
2	2	6	2	4
1	1	3	1	2

$$(3, 10, 8, 14, 7, 5, 2)$$

↑

Method 2

$$Y_{xy}(k) = \sum_{n=-\infty}^{\infty} x(n) \cdot y(n-k)$$

$$Y_{xy}(-3) = \sum x(n) y(n+3)$$

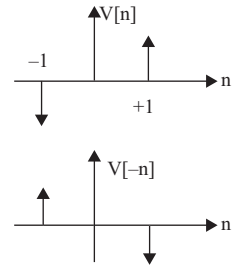
$$= x(0) y(3) = 3$$

$$Y_{xy}(-2) = \sum x(n) y(n+2)$$

$$= x(0) y(2) + x(1) y(3) = 1 + 9 = 10.$$

$$47. E[g(X)] = \int_{-\infty}^{\infty} g(x) f_x(x) dx$$

48.



$$V[n] + V[-n] = 0$$

Therefore $y[n] = v[n] + v[-n] = 0$

49. Maximum length of the sequence for

$$x_1(n) * x_2(n) \text{ is } n_1 + n_2 - 1 = 5 + 7 - 1 = 11.$$

$$50. y(n) = x[n] + h[n] = \sum_{k=-\infty}^{\infty} x(k) h(n-k)$$

$$\therefore y(2) = \sum x(k) h(2-k)$$

$$= x(0)h(2) + x(1)h(1) + x(2)h(0) = \frac{5}{4}$$

Total length of sequence is, $3 + 3 - 1 = 5$

Second Method

$$h[n] = \delta[n] + \frac{1}{2}\delta[n-1] + \frac{1}{4}\delta[n-2] + 0\delta[n-3] + \dots$$

$$x[n] = \delta[n] + 0.8\delta[n-1] + \delta[n-2] + 0.8\delta[n-3] + \dots$$

$$y[n] = x[n] * h[n]$$

$$[\delta[n] + \delta[n-2]] *$$

$$\left[\delta[n] + \frac{1}{2}\delta[n-1] + \frac{1}{4}\delta[n-2] \right]$$

$$= \delta[n] \delta[n] + \delta[n] \frac{1}{2} \delta[n-1] + \delta[n]$$

$$\frac{1}{4} \delta[n-2]$$

$$+ \delta[n-2] \delta[n] + \delta[n-2]$$

$$\delta[n-1] + \delta[n-2] \frac{1}{4} \delta[n]$$

$$= \delta[n] + \frac{1}{2} \delta[n-1] + \frac{1}{4} \delta[n-2]$$

$$+ \delta[n-2] + \frac{1}{2} \delta[n-3] + \frac{1}{4} \delta[n-4]$$

$$= \delta[n] + \frac{1}{2} \delta[n-1] + \frac{5}{4} \delta[n-2] + \frac{1}{2}$$

$$\delta[n-3] + \frac{1}{4} \delta[n-4]$$

$$51. \quad y[n] = x[n] * h[n] = \sum_{k=-\infty}^{\infty} x[k] h[n-k]$$

$$= \sum_{k=-\infty}^{\infty} a^k u[k] b^{n-k} u[n-k]$$

$$52. \quad y[n] = \sum_{k=0}^{\infty} x[k]$$

$$Y[z] = \sum_{n=0}^{\infty} x[n] z^{-1} = \frac{X(z)}{1-z^{-1}}$$

53. Method 1

$$X(t) = 5 \cos 400 \pi t$$

$$= \frac{5}{2} [e^{j400\pi t} + e^{-j400\pi t}]$$

$$X(\omega) = \frac{5}{2}$$

$$[2\pi \delta(\omega - 400\pi) + 2\pi \delta(\omega + 400\pi)]$$

$$x(f) = \frac{5}{2} [\delta(f - 200) + \delta(f + 200)]$$

Now $x(t)$ is sampled at the rate of 300 Hz

The sampled signal

$$X_s(f) = f_s \sum x(f - nf_s)$$

Hence $X_s(f)$ will consist of impulse of strength 750 located at $\pm 200 n f_s$

where $n = 0, 1, 2, \dots$

The few location are besides ± 200

$$200 - 300 = -100$$

$$200 + 300 = 500$$

$$-200 - 300 = -500$$

$$-200 + 300 = 100$$

$$200 - 2 \times 300 = -400$$

$$200 + 2 \times 300 = 1000$$

$$-200 - 2 \times 300 = -100$$

$$-200 + 2 \times 300 = +400$$

Filter have circuit of frequency 150 Hz

Therefore only 100 Hz signal will pass.

Second Method

$$y(t) = x(t) x \cos 2 \pi \cdot 300 t$$

$$= 5 \cos 400 \pi t x \cos 600 \pi t$$

$$= \frac{5}{2} [\cos 2.100 \pi t] = 100 \text{ Hz.}$$

L. P. F. of cut off frequency = 150 Hz

$$Y(t) = \frac{5}{2} [\cos 2.100 \pi t] = 100 \text{ Hz.}$$

$$54. \quad X(z) = \frac{z}{(z-2)(z-3)} \quad |z| < 2$$

$$\frac{X(z)}{z} = \frac{1}{(z-2)(z-3)}$$

$$\frac{X[z]}{z} = \frac{1}{z-3} - \frac{1}{z-2}$$

$$X[z] = \frac{z}{z-3} - \frac{z}{z-2} \quad |z| < 2$$

$$X(z) = \frac{1}{1-3z^{-1}} - \frac{1}{1-2z^{-1}} \quad |z| < 2$$

$$55. \quad R_x(\tau) = E[X(t+\tau)X(t)]$$

$$\therefore R_x(0) = E[X^2(t)]$$

Thus, $R_x(0)$ is the mean-square value of the process.

57. Non-linear.

$$y(t) = a x(t) + b$$

$$m y_1(t) + n y_2(t) + m x_1(t) + n x_2(t)$$

$$\therefore \text{Non-linear.}$$

$$58. \quad = \frac{-1}{s^2(s+2)}$$

Convolution in time domain is equivalent to multiplication in frequency domain

$$x(t) = x_1(t) \times x_2(t)$$

$$X(s) = X_1(s) \cdot X_2(s)$$

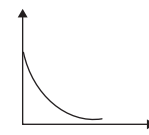
$$LT[x(t) = -e^{2t} u(t) \times t u(t)]$$

$$= \frac{-1}{s+2} \cdot \frac{1}{s^2}$$

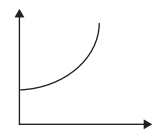
$$= \frac{-1}{s^2(s+2)}$$

60.

$$|a| < 1$$



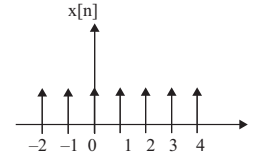
$$a > 1$$



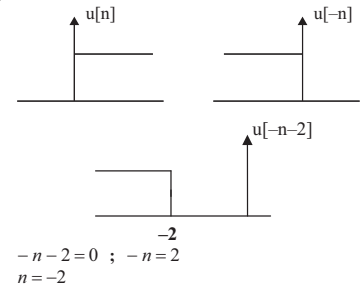
62.

(1)

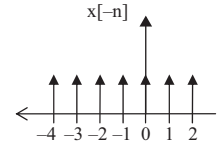
$$x[n] = \begin{cases} 0 & \text{for } n < -2 \text{ or } n > 4 \\ 1 & \text{Otherwise} \end{cases}$$



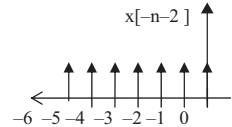
(2)



(3)

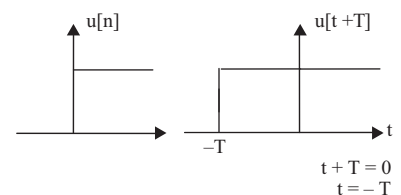
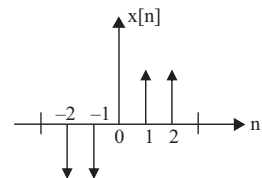


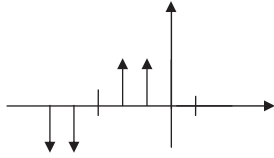
(4)



63.

$$x[n] = \begin{cases} 1, & n = 1, 2 \\ -1, & n = -1, -2 \\ 0, & n = 0 \text{ and } |n| > 2 \end{cases}$$





64. Frequency shifting property

$$f(t) \leftrightarrow F(\omega)$$

$$FT f(t) e^{j\omega_0 t} = \int_{-\infty}^{\infty} f(t) e^{-j(\omega - \omega_0)t} dt$$

$$\int_{-\infty}^{\infty} f(t) e^{-j(\omega - \omega_0)t} dt = F(\omega - \omega_0)$$

$$\text{Then if } x(t) \rightarrow \frac{2}{\omega} \sin(\pi\omega)$$

$$e^{j5t} x(t) \rightarrow \frac{2}{\omega - 5} \sin[\pi(\omega - 5)].$$

$$65. \frac{A}{s+1} + \frac{B}{s+2} + \frac{C}{(s+2)^2} + \frac{D}{(s+2)^3}$$

$$A = \frac{8s+10}{(s+2)^3} \Big|_{s=-1} = \frac{8 \times -1 + 10}{1} = 2$$

$$D = \frac{8s+10}{(s+1)} \Big|_{s=-2} = \frac{8 \times -2 + 10}{-1} = 6$$

$$8s+10 = A(s+2)^3 + B(s+2)^2(s+1) + C(s+1)(s+2) + D(s+1)$$

$$8s+10 = A(s^3+8+6s^2+12s)$$

$$+ B(s^3+4s+4)(s+1)$$

$$+ C(s^2+3s+2) + D(s+1)$$

$$8s+10 = A(s^3+8+6s^2+12s)$$

$$+ B(s^3+5s^2+8s+4)$$

$$+ C(s^2+3s+2) + D(s+1)$$

Comparing s^3

$$A+B=0 \Rightarrow B=-A=-2$$

Comparing s^2

$$6A+5B+C=0$$

$$C=-6A-5B=-6 \times 2 - 5 \times -2$$

$$=-12+10=-2$$

$$C=-2$$

$$F(s) = \frac{2}{s+1} - \frac{2}{s+2} - \frac{2}{(s+2)^2} + \frac{6}{(s+2)^3}$$

$$66. X(s) = e^{-s} \left[\frac{-2}{s(s+2)} \right]$$

$$\text{Final Value } x(\infty) = \lim_{s \rightarrow 0} [s X(s)]$$

$$= \lim_{s \rightarrow 0} \left[s \times \frac{-2}{s(s+2)} e^{-s} \right]$$

$$= \lim_{s \rightarrow 0} \left[\frac{-2}{(s+2)} e^{-s} \right] = \frac{-2}{2} e^0 = -1$$

$$\text{Initial Value } x(0) = \lim_{s \rightarrow \infty} [s X(s)]$$

$$= \lim_{s \rightarrow \infty} \left[s \times \frac{-2}{s(s+2)} e^{-s} \right]$$

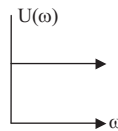
$$= \lim_{s \rightarrow \infty} \left[\frac{-2}{(s+2)} e^{-s} \right]$$

Divide by s

$$= \lim_{s \rightarrow \infty} \left[\frac{-2/s}{1+(2/s)} e^{-s} \right]$$

$$= \frac{0}{1+0} \times 0 = 0.7$$

67.



$$u(t) \rightarrow \frac{2}{j\omega} + \pi\delta(\omega);$$

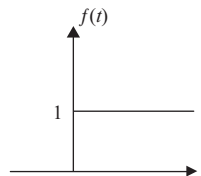
$$U(\omega) \rightarrow \frac{1}{\pi t} + \frac{1}{2} \delta(t).$$

$$68. F(j\omega) = \int g(t) e^{-j\omega t} dt$$

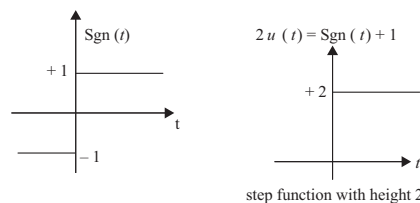
$$F^*(-j\omega) = \int g(t) e^{-j\omega t} dt = F(j\omega)$$

$$69. f(t) = u(t) = 0 \quad ; \quad t < 0$$

$$= 1 \quad ; \quad t > 0$$



Consider the following function



step function with height 2

$$2u(t) = 1 + \text{Sgn}(t)$$

$$u(t) = 1/2 [1 + \text{Sgn}(t)] \quad ; \quad t > 0$$

$$= 0 \quad ; \quad t < 0$$

$$FT[u(t)] = (1/2) FT[\text{sgn}(t) + 1]$$

$$= (1/2) [(2/j\omega) + 2\pi\delta(\omega)]$$

$$FT[u(t)] = (1/j\omega) + \pi\delta(\omega)$$

$$70. \lim_{t \rightarrow \infty} f(t) = \lim_{s \rightarrow 0} sF(s)$$

$$\lim_{s \rightarrow 0} = \frac{s(2s+1)}{s^4+8s^3+16s^2+s}$$

$$\lim_{s \rightarrow 0} = \frac{2s+1}{s^3+8s^2+16s+1} = 1$$

Note:1. for $\lim_{s \rightarrow 0}$ put the value of s directly2. for $\lim_{s \rightarrow \infty}$ Divide the $N(s)$ and $D(s)$ by highest power of s and then put the value of s .

71. Multiplication of two signals in frequency domain is equivalent to their convolution in time domain.

$$73. i_{rms} = \sqrt{4+1+25}$$

$$\text{Power} = i^2 R = 30 \times 10 = \mathbf{300}$$

$$74. y(n) - 2y(n-1) + y(n-2)$$

$$= x(n) - x(n-1)$$

for $n=0$,

$$y(0) - 2y(-1) + y(-2) = x(0) - x(-1)$$

$$\therefore y(0) = x(0) - x(-1)$$

For $n=1$,

$$y(1) - 2y(0) + y(-2) = x(1) - x(0)$$

$$\therefore y(1) = x(1) + x(0) + 2x(0) - 2x(-1)$$

$$= x(1) + x(0) - 2x(-1)$$

For $n=2$

$$y(2) = x(2) - x(1) + 2y(1) - y(0)$$

$$\therefore = x(2) - x(1) + 2x(1) + 2x(0) - 4x(-1) - x(0) + x(-1)$$

$$= x(2) + x(1) + x(0) - 3x(-1)$$

$$= \delta(2) + \delta(1) + \delta(0) - 3\delta(-1)$$

Taking that $\delta(n)$ is an impulse function; and that area under each of the $\delta(2)$, $\delta(1)$, $\delta(0)$ and $\delta(-1)$ is unity, RHS becomes zero.

$$78. V = \sqrt{1^2 + 4^2 + 2^2} = \sqrt{1+16+4}$$

$$= \sqrt{21}$$

$$P = (V^2/R) = \mathbf{21}$$

$$79. F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t} dt$$

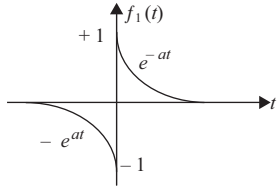
$$= \int_{-\infty}^{\infty} f(t) e^0 dt = \int_{-\infty}^{\infty} f(t) dt$$

$$80. \omega_0 = \frac{2\pi}{T} = \frac{\pi}{4}$$

$$\Rightarrow T = \mathbf{8 \text{ sec}}$$

LEVEL 3

1. FT of $\text{sign}(t)$ does not exist since $\int f(t) dt \rightarrow \infty$. We will find its FT under some limits. Consider the following function.



$$f(t) = \lim_{a \rightarrow 0} f_1(t); \quad F(\omega) = \lim_{a \rightarrow 0} f_1(\omega)$$

$$f_1(t) = -e^{at}; \quad t < 0$$

$$= +e^{-at}; \quad t > 0$$

$$F_1(\omega) = \int_{-\infty}^0 -e^{at} e^{-j\omega t} dt + \int_0^{\infty} e^{-at} e^{-j\omega t} dt$$

$$= \int_{-\infty}^0 -e^{(a-j\omega)t} dt + \int_0^{\infty} e^{-(a+j\omega)t} dt$$

$$= \left[\frac{-e^{(a-j\omega)t}}{a-j\omega} \right]_{-\infty}^0 + \left[\frac{e^{-(a+j\omega)t}}{-(a+j\omega)} \right]_0^{\infty}$$

$$= \frac{-1}{a-j\omega} (1-0) + \frac{1}{-(a+j\omega)} (0-1)$$

$$= \frac{-1}{a-j\omega} + \frac{-1}{-(a+j\omega)}$$

$$= \frac{-a-j\omega + a-j\omega}{a^2 + \omega^2} = \frac{-2j\omega}{\omega^2 + a^2}$$

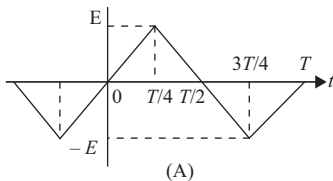
$$F(\omega) =$$

$$\lim_{a \rightarrow 0} \frac{-2j\omega}{\omega^2 + a^2} = \frac{-2j\omega}{\omega^2} = \frac{2}{j(\omega)}$$

$$= \frac{2}{0 + j\omega}$$

$$\text{FT} [\text{Sgn}(t)] = (2/j\omega); |F(\omega)| = (2/\omega) \circ$$

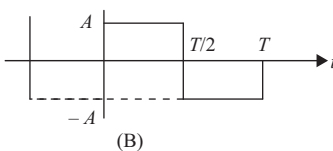
2. If $f(t)$ is an odd function.



$$-f(t) = f(-t); \text{ Then,}$$

$$a_o = 0; \quad a_n = 0$$

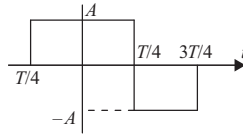
$$b_n = \frac{4}{T} \int_0^{T/2} f(t) \sin(n\omega_o t) dt$$



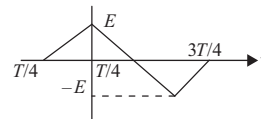
If $f(t)$ is having half wave symmetry
 $-f(t \pm T/2) = f(t)$: Then $a_o = 0$

$$a_n = \frac{4}{T} \int_0^{T/2} f(t) \cos(n\omega_o t) dt$$

$$b_n = \frac{4}{T} \int_0^{T/2} f(t) \sin(n\omega_o t) dt$$



Even symmetry



Even symmetry
(D)

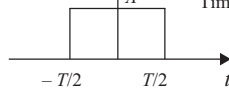
3. The Fourier transform of gate function is sampling function

Gate function

$$f(t) = A; \quad -T/2 < t < T/2$$

$$= 0; \quad \text{other wise}$$

$$\text{Time period} = T$$



$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t} dt = \int_{-T/2}^{T/2} A e^{-j\omega t} dt$$

$$= A \left[\frac{e^{-j\omega t}}{-j\omega} \right]_{-T/2}^{T/2} = \frac{-A}{j\omega} [e^{-j\omega T/2} - e^{+j\omega T/2}]$$

$$= \frac{A}{j\omega} \left(\frac{e^{j\omega T/2} - e^{-j\omega T/2}}{2j} \right) (2j)$$

$$= \frac{2A}{\omega} \sin\left(\frac{\omega T}{2}\right) = \frac{2A}{\omega} \sin\left(\frac{\omega T}{2}\right) \left(\frac{\omega T}{2}\right)$$

$$F(\omega) = AT (\sin x/x) \dots \text{ where, } x = \omega T/2$$

$$= \text{sampling function}$$

In present case $A = 1$ and time period is $2T$

$$\text{Therefore } F(\omega) = 1 \times 2T (\sin x/x) \dots$$

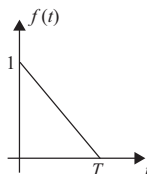
$$\text{where, } x = \omega T$$

$$= \frac{2 \sin \omega T_1}{\omega}$$

The present function is shifted function by T_1

$$\text{Therefore, } F(\omega) = \frac{2 \sin \omega T_1}{\omega} e^{-j\omega T_1}$$

- 4.

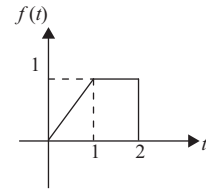


$$f(t) = u(t) - (1/T) r(t) + (1/T) r(t - T)$$

$$\therefore F(s) = \frac{1}{s} - \frac{1}{Ts^2} + \frac{1e^{-sT}}{Ts^2}$$

$$= \frac{1}{Ts^2} e^{-Ts} - 1 + Ts$$

5. Condition $f(t) = (-t)$ implies that its has rotational/odd symmetry.
7. Fourier series for the given square wave is as below:
- $$V(t) = \frac{4V}{\pi} \left(\sin x + \frac{\sin 3x}{3} + \frac{\sin 5x}{5} + \dots \right)$$
- therefore answer is $= (4V/\pi)$
8. Only sin function, as it has the odd symmetry.
10. $\omega_o = \frac{2\pi}{T} = \frac{\pi}{4}$
- $$\Rightarrow T = 8 \text{ sec}$$
- 11.

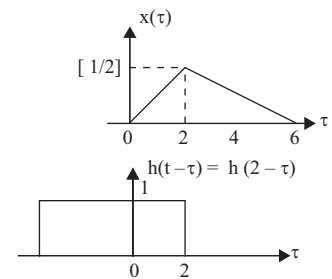


$$f(t) = r(t) - r(t-1) - u(t-2)$$

$$F(s) = \frac{1}{s^2} - \frac{1e^{-s}}{s^2} - \frac{1e^{-2s}}{s}$$

$$= (1/s^2) (1 - e^{-s} - se^{-2s})$$

- 13.



The above figure demonstrate the process of convolution. The output $y(t)$ of the system is given by

$$y(t) = \int x(\tau) h(t-\tau) d\tau$$

$$y(2) = \int x(\tau) h(2-\tau) d\tau$$

$$= \int_1^2 \left[\left(\frac{1}{4} \right) \cdot \tau \right] \cdot 1 \cdot d\tau$$

$$= \frac{1}{4} \times \frac{\tau^2}{2} \Big|_1^2 = \frac{1}{4} [2-0] = \frac{1}{2}$$

14. Mean $\bar{x} = \int_{-1}^3 x p(x) dx = \int_{-1}^3 x \left(\frac{1}{4} \right) dx$

$$= \frac{1}{4} \left(\frac{x^2}{2} \right) \Big|_{-1}^3 = \frac{1}{4 \times 2} [9-1] = \frac{8}{8} = 1$$

$$\text{Variance } \sigma^2 = \int_{-1}^3 x^2 p(x) - (x')^2$$

$$= \text{Second moment} - (\text{mean})^2$$

$$= \frac{1}{4} \int_{-1}^3 x^2 dx - (x')^2$$

$$= \frac{1}{4} \left(\frac{x^3}{3} \right)_{-1}^3 - (x')^2$$

$$= \left(\frac{1}{12} \right) (27 + 1) - 1$$

$$= \frac{1}{12} \times 28 - 1$$

$$= \frac{7-3}{3} = \frac{4}{3}$$

15. $W_1 = 1$ for 0 to $\frac{T}{2}$

$$= -1 \text{ for } \frac{T}{2} \text{ to } T$$

W_1 will have integral form

$$\frac{1}{T_p} \int_{\frac{T_p}{2}}^{\frac{T_p}{2}} 1 e^{-j\omega_p t} dt$$

$$\text{i.e., } W_1 \propto \frac{1}{n}$$

$$W_2 \rightarrow \text{is linear for } 0 \text{ to } \frac{t}{4}$$

$$\rightarrow \text{is linear for } \frac{t}{4} \text{ to } \frac{3t}{4}$$

$$\rightarrow \text{is linear for } \frac{3t}{4} \text{ to } T$$

W_2 will have integral form

$$\frac{1}{T_p} \int_{\frac{T_p}{2}}^{\frac{T_p}{2}} n \cdot e^{-jn\omega_p t} dt$$

$$\text{i.e., } W_2 \propto \frac{1}{n^2}$$

16. $x_1(t) = u(t) - u(t-1)$

$$X_1(s) = \frac{1}{s} [1 - e^{-s}]$$

$$x_2(t) = u(t) - u(t-2)$$

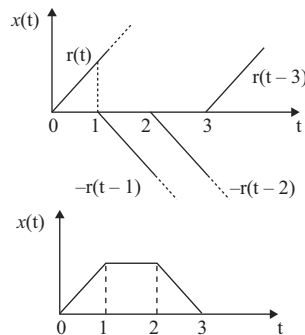
$$X_2(s) = \frac{1}{s} [1 - e^{-2s}]$$

$$x(t) = x_1(t) * x_2(t) \rightarrow X_1(s) X_2(s)$$

$$= \frac{1}{s} [1 - e^{-s}] \times \frac{1}{s} [1 - e^{-2s}]$$

$$= \frac{1}{s^2} [1 - e^{-s} - e^{-2s} + e^{-3s}]$$

$$x(t) = r(t) - r(t-1) - r(t-2) + r(t-3)$$



17. Equation of the line joining (-20) and $(1.00.25)$ is

$$\frac{Y-0}{X+2} = \frac{0.25-0}{1+2}$$

$$\therefore \left(\frac{0.25}{3} \right) (x+2) = \frac{1}{12} (x+2)$$

Thus in $-2 \leq x \leq 1, f(x) = [1/12] (x+2)$

$$\therefore f(x) = f'(x) = \frac{1}{12}$$

$$\text{Now, } P(X=1) = \int_{-2}^1 f(x) dx$$

$$= \int_{-2}^1 \left(\frac{1}{12} \right) dx = \frac{1}{12} (x) \Big|_{-2}^1 = \frac{1}{4}$$

18. $s(t) = 1 [1 + 2 \cos \omega_s t + 2 \cos 2\omega_s t + \dots]$

$$x(t) = \cos^2(4\pi \times 10^3 t)$$

$$= \frac{1 + \cos 8\pi \times 10^3 t}{2}$$

$$\omega_s = \frac{2\pi}{0.1 \times 10^{-3}}$$

$$= 2\pi \times 10 \times 10^3$$

$$s(t) * x(t) = \int_{-\infty}^{\infty} s(\tau) X(\tau-t) d\tau$$

$$= \int_{-\infty}^{\infty} 10 \times 10^3 \left[\frac{1 + 2 \cos \omega_s t}{2} \right] \times$$

$$\left(\frac{1 + \cos 8\pi \times 10^3 t}{2} \right) dt$$

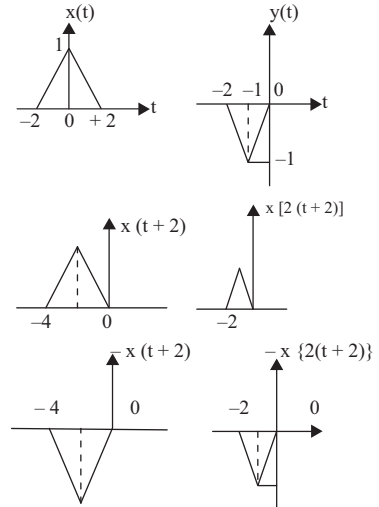
So, frequencies present will be $f_s \pm f_m, 2f_s \pm f_m, 3f_s \pm f_m$

$$f_s = 10 \text{ kHz}$$

$$f_m = 8\pi \times 10^3 = 4 \text{ kHz}$$

Hence 14 kHz sinusoidal signal will be present

19.



$$x(t-t_0) \rightarrow X(f) e^{-j2\pi f t_0}$$

$$X(a t) \rightarrow [1/a] X(f/a)$$

$$y(t) = -x[2(t+2)] \rightarrow -[1/2]$$

$$X(f/2) e^{-j2\pi f \times 2/2} \rightarrow -\frac{1}{2} \times \left(\frac{f}{2} \right) e^{j2\pi f}$$

20. $H(s) = \frac{K(s-1-j)(s-1+j)(s-1)}{(s+1-j)(s+1+j)(s+1)}$

$$= \frac{K(s^2 - 2s + 1)(s-1)}{(s^2 + 2s + 1)(s+1)}$$

$$= \frac{K(s-1)^2(s-1)}{(s+1)^2(s+1)} = \frac{K(s-1)^2}{(s+1)^2}$$

$$= \frac{K(\tan^{-1}[1/-1])^2}{\tan[1/1]^2} = K \angle \text{constant angle}$$

All pass filter having constant magnitude.

* Since all pole have corresponding zero in the right hand side of s-plane. Hence it is a all pass filter. This is the characteristic of all pass filter

21. Power spectrum $G(\omega) = |F(\omega)|^2$

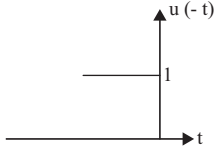
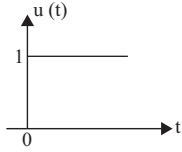
$$\text{Since } \sin^2 a t = \frac{1}{2} (1 + \cos 2 a t)$$

In power spectrum term, the frequency becomes double. In power spectrum figure, the frequency is 2 kHz but originally this will have the frequency of 1 kHz. Hence minimum sampling rate of this deterministic signal is $2 \times \text{kHz} = 2 \text{ kHz}$

22. $x_{\text{even}}(t) = \frac{x(t) + x(-t)}{2}$

$$x_{\text{odd}}(t) = \frac{x(t) - x(-t)}{2}$$

$$\text{Even part} = \frac{u(t) + u(-t)}{2} = [1/2]$$



$$\text{odd part} = \frac{u(t) - u(-t)}{2} = \frac{x(t)}{2}$$

23. For causal system, impulse response
 $h(t) = 0$, for $t < 0$,
24. $y(2) = x(0) = 2$
 $y(4) = x(1) = 1$
 $y(n) = x\left(\frac{n}{2} - 1\right)$ for even i.e., $n = -2, 0, 2$
 $n = -2, y(-2) = x\left[\frac{-2}{2} - 1\right] = x[-2] = \frac{1}{2}$
 $n = 0, y(0) = x\left[\frac{0}{2} - 1\right] = x[-1] = 1$
 $n = 2, y(2) = x\left[\frac{2}{2} - 1\right] = x[0] = 2$
 $n = 4, y(4) = x\left[\frac{4}{2} - 1\right] = x[1] = 1$

$$25. y(2n) = \left\{ \frac{1}{2}, \frac{1}{2}, 2, 1, \frac{1}{2}, \dots \right\}_{n=0}$$

Fourier transform of $y(n)$ is $\sum_{n=-\infty}^{\infty} y(n) e^{-j\omega n}$

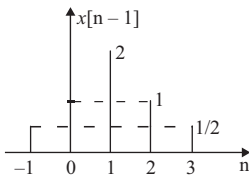
$$FT[y(2n)] = \left[\frac{1}{2} \right] e^{j\omega} + 1 + 2e^{-j\omega} + e^{j2\omega} + \left[\frac{1}{2} \right] e^{-j3\omega}$$

$$FT[y(2n)] = e^{j\omega} [\cos 2\omega + 2 \cos \omega + 2]$$

Another way

$$y[n] = x\left[\frac{n}{2} - 1\right]$$

$$y[2n] = x[-1]$$



$$y[2n] = \frac{1}{2} \delta[n+1] + \delta[n] + 2\delta[n+1] + \delta[n-2] + \frac{1}{2} \delta[n-3]$$

Taking Z-transform

$$ZT[y(2n)] = \frac{1}{2}z + 1 + 2z^{-1} + z^{-2} + \frac{1}{2}z^{-3}$$

$$\text{Put } z = e^{j\omega}$$

$$\begin{aligned} &= \frac{1}{2}e^{j\omega} + 1 + 2e^{-j\omega} + e^{-2j\omega} + \frac{1}{2}e^{-3j\omega} \\ &= e^{-j\omega} \left[\frac{1}{2}e^{2j\omega} + e^{j\omega} + 2 + e^{-j\omega} + \frac{1}{2}e^{-2j\omega} \right] \\ &= e^{-j\omega} \left[\frac{e^{2j\omega} + e^{-2j\omega}}{2} + e^{j\omega} + e^{-j\omega} + 2 \right] \\ &= e^{-j\omega} [\cos 2\omega + \cos \omega + 2] \end{aligned}$$

26. System $[1/(s+1)]$ gives change in output as

$$\frac{1}{\sqrt{(1+1)}} \angle -\tan^{-1} \frac{1}{1}$$

$$\frac{1}{\sqrt{2}} \angle -45^\circ$$

Since input is sinusoidal output will be sinusoidal with same frequency but change in amplitude and phase.

Therefore, output $y(t) = [1/\sqrt{2}] \sin [t - (\pi/4)]$

27. Sample space of random variable $X = (-\infty \text{ to } \infty)$

After transformation sample space of random variable $Y = (0 \text{ to } 1)$

$$\text{Hence } f_Y(y) = A f_X(y) + B [f_X(y-1)]$$

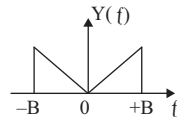
28. This diagram represent SSB generation by phase shift method

For USB, $r(t) = m(t) \cos \pi Bt - m'(t) \sin 2\pi Bt$

For LSB, $r(t) = m(t) \cos \pi Bt + m'(t) \sin 2\pi Bt$

Since $y(t)$ is sum of both

$\therefore$ It is LSB generator and its Fourier transform $Y(f)$ is given as



CHAPTER 4

LEVEL 1

4. Since the zeros are the complex conjugate of poles in the s -plane, the circuit is all pass filter and the magnitude of the response of the function is independent of frequency.
5. The given function represent LC driving point function for which the pole and zero must alternate rest other properties are also required.

Properties L-C Impedance Function

1. The impedance $\{Z_{LC}(s)\}$ or the Admittance $\{Y_{LC}(s)\}$ of these function are odd to even or even to odd polynomials
2. The poles and zeros are simple and lie on the $j\omega$ axis.
3. The Poles and zeros and inter lace on the $j\omega$ axis.
4. The highest power of numerator $N(s)$ and denominator $D(s)$ must differ by unity, the lowest power also differ by unity.
5. There must be either a zero or pole at the origin and infinity.
6. In cascaded network $ABCD$ are multiplied.

$$7. V(s) = \frac{s+2}{s(s+1)}$$

$$\text{Initial value } V(0) = \lim_{s \rightarrow \infty} sV(s)$$

$$\begin{aligned} &= \lim_{s \rightarrow \infty} \frac{s(s+2)}{s(s+1)} \\ &= \lim_{s \rightarrow \infty} \frac{1+2/s}{1+1/s} = 1 \end{aligned}$$

$$\text{Final value } V(\infty) = \lim_{s \rightarrow 0} sV(s)$$

$$= \lim_{s \rightarrow 0} \frac{s(s+2)}{s(s+1)} = 2$$

9. For a system to be stable all the poles of the transfer function must be in the left half of the s -plane.
10. If the step response of an initially relaxed circuit is known, then the ramp response can be obtained by integrating the step response.
11. Capacitor is energised by symmetrical square wave current source, then the steady-state voltage across the capacitor will be a square wave.
13. As can be seen, the dual network has three meshes, although the elements B and D can be reduced to one and similarly the elements C and E can be reduced to a single element leading to only one mesh.
14. **The circuit work as differentiator or integral.** The capacitor will charge during positive half cycle and discharge during negative half cycle. Under both conditions, the voltage across C will be exponential nature. Thus neither across R , nor a across C , the voltage will be a square one.

$$15. \text{ Since } Q = \frac{f_o}{f_2 - f_1} \text{ and } Q = \frac{\omega_o L}{R}, \text{ it}$$

implies a very low resistance to the coil and hence a low power losses.

$$16. Q = \frac{\omega_o L}{R} \text{ and } Q = \frac{\omega_o}{\omega_2 - \omega_1} \text{ if the circuit}$$

referred to above is a series R - L - C circuit and Q factor specified so for resonance condition, then power factor of the circuit at resonance is high.

18. Number of nodes = 10

Number of different node pair voltages

$$= C_2^{10} = \frac{10!}{2! \times 8!} = \frac{10 \times 9 \times 8!}{2 \times 8!} = 45$$

and No of KCL equation = $n - 1 = 10 - 1 = 9$

19. Maximum power factor is one.

- 20.
- $Z_{12} = \frac{V_2}{I_1} = Z_{21}$
- for reciprocal network.

21. For series network the
- z
- parameter are added up.
- $Z = Z_1 + Z_2$

22. IF the value of resistor are double
-
- The current decrease finally Node voltage remains unchanged.

- 23.
- $M = K \sqrt{L_1 L_2}$
-
- $\therefore K = \frac{0.015}{\sqrt{0.09 \times 0.01}} = \frac{1}{2}$

24. Superposition principle is applicable to only linear circuits.

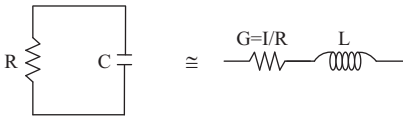
$$\text{Power } P = I^2 R \\ = V^2 / R$$

It cannot be applied directly to computation of power as power is square of current or voltage.

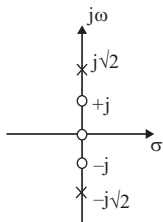
25. At,
- $t = \infty$
- ,
- $L \rightarrow$
- Short circuit

Current take easy path, no current flow through resistor.

- 26.



- 27.
- $Z(s) = \frac{s(s^2 + 1)}{s^2 + 4}$



Poles and zero do not alternate on imaginary axis

28. Energy stored in capacitor

$$W_e = \frac{1}{2} C V^2$$

Energy stored/volume

$$w_e = \lim_{\Delta v \rightarrow 0} \frac{\Delta W_e}{\Delta V} = \frac{1}{2} \bar{D} \cdot \bar{E}$$

$$w_e = \frac{1}{2} \epsilon E^2$$

29. Impedance function is series circuit

$$X_L = \omega L \text{ as } \omega \text{ increase } X_L \uparrow \uparrow$$

$$Z_{RL}(\infty) \gg Z_{RL}(0)$$

32. In a four-branch parallel circuit, 50 mA current flows in each branch. If one of the branches opens, the currents in the other branches are unaffected as
- V
- across each resistance remains constant

34. Properties of Tree

1. It contain all the node of the graph
2. If a Graph contains n nodes then its tree will have $(n - 1)$ branches.
3. There is no closed path & hence a tree is circuit less.

Number of Branches in tree = Number of KCL equation = $(n - 1)$ Number of Links or chords = Number of KVL equation = $b - (n - 1) = b - n + 1$

35. Fundamental circuit set given KCL equation.

Number of KCL equation = $n - 1 = 8 - 1 = 7$

36. Number of independent loops gives the number of KVL equation
-
- $= b - n + 1 = 11 - 6 + 1 = 12 - 6 = 6$

38. Quality factor

$$Q = \frac{\omega_o L}{R} = \frac{L}{R} \sqrt{\frac{1}{LC}} = \frac{1}{R} \sqrt{\frac{L^2}{LC}}$$

$$\text{Therefore } Q = \frac{1}{R} \sqrt{\frac{L}{C}}$$

39. Tellegen's Theorem is appreciable for any lumped network having elements which are linear or non-linear active or passive time varying or time invariant. The theorem is based on the two Kirchhoff's laws. It is completely independent of the nature of elements and is only concerned with the graph of the network. Sum of the power delivered to all branches of a network is zero.

$$\sum_{K=1}^b V_K i_K = 0 \quad ; \quad \sum_{K=1}^b V_K(t) i_K(t) = 0$$

The theorem is not concerned with the type of circuit element.

44. Since
- $Q = [L\omega_o/R]$
- , it implies a vary low resistance of the coil and hence low power losses.

- 45.
- $Q = [L\omega_o/R]$
- and bandwidth is inversely proportional to
- Q
- , it the circuit referred to above is a series
- R
-
- L
-
- C
- circuit and
- Q
- factor specified is for resonance condition, then power factor of the circuit at resonance in high

- 50.



$$V_s = A V_R - B I_R$$

$$I_s = C V_R - D I_R$$

Voltage ratio transfer function is

$$[V_R/V_s] = [1/A]$$

When, $I_R = 0$ When two networks are connected in cascade, the two $ABCD$ parameter matrices get multiplied

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} A_1 & B_1 \\ C_1 & D_1 \end{pmatrix} \begin{pmatrix} A_2 & B_2 \\ C_2 & D_2 \end{pmatrix}$$

$$\begin{pmatrix} A_1 A_2 + B_1 C_2 & A_1 B_2 + B_1 D_2 \\ C_1 A_2 + D_1 C_2 & C_1 B_2 + D_1 D_2 \end{pmatrix}$$

- 51.
- $\frac{V_0(s)}{V_1(s)} = \frac{1/Cs}{R + 1/Cs}$

$$= \frac{1}{1 + RCs}$$

54. Admittance

$$Y(s) = \frac{I(s)}{V(s)} = \frac{N(s) \rightarrow \text{Zeros}}{D(s) \rightarrow \text{Poles}}$$

It mean at pole frequency, $V = 0$

55. For transfer function realization separate rules are there, Reactance function means only
- L
- and
- C
- but impedance represent combination of
- R
- ,
- L
- ,
- C
- .

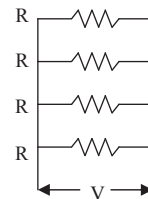
- 56.
- $P = I^2 R = \frac{V^2}{R}$
- is a non-linear response.

57. Series resonance is a low-impedance resonance i.e.
- $Z_{in}(\omega)$
- is a minimum.

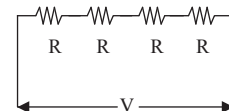
- 58.
- $\cos \phi = \cos \tan^{-1} \left(\frac{W_1 - W_2}{W_1 + W_2} \sqrt{3} \right)$
-
- $= \cos \tan^{-1} \sqrt{3} = 0.5$

When the p.f is 0.5, one of the wattmeter reads zero and the other reads total power.

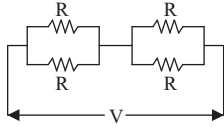
- 59.



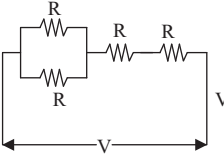
$$R_i = \frac{R}{4} ; P = \frac{V^2}{R/4} = \frac{4V^2}{R}$$



$$R_i = 4R ; P = \frac{V^2}{4R}$$



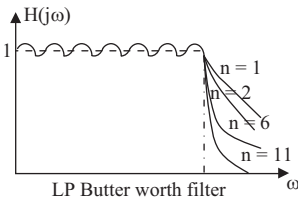
$$R_T = \left(\frac{R}{2}\right) + \left(\frac{R}{2}\right) = R; \quad P = \left(\frac{V^2}{R}\right)$$



$$R_T = \left(\frac{R}{2}\right) + 2R = 2.5R; \quad P = \frac{V^2}{2.5R}$$

65. An attenuator is to reduce, by known amount, the voltage, current or power between its properly terminated input and output ports. An attenuator is a two-port resistive network and its propagation function is real. The attenuation is independent of frequency. Attenuators may be symmetrical or asymmetrical. An attenuator of constant attenuation is called a 'pad'.

68. Butter worth filter has essentially flat amplitude response in the pass band and an attenuation rate beyond cut-off of 20 dB/decoder for a single pole filter. Transient response is much better than for a comparable Chebyshev filter.

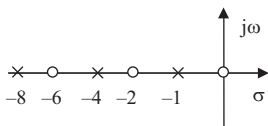


70. RC Driving point admittance function.

Properties:

1. The poles and zeros lie in the -ve real axis and they alternate.
2. The singularity nearest to or at the origin must be zero and singularity nearest to infinity must be poles.
3. The residue of pole must be real and positive.

$$F(s) = \frac{s(s+2)(s+6)}{(s+1)(s+4)(s+8)}$$



This F(s) represent either a RC function or RL admittance driving it impedance function

$$71. \quad T(s) = \frac{s}{s+a}$$

$$\text{at } s \rightarrow 0, \quad T(s) = \frac{0}{a} = 0$$

$$\text{at } s \rightarrow \infty, \quad T(s) = \frac{(s/s)}{(s/s) + (a/s)} = \frac{1}{1+0} = 1$$

Result HPF.

$$73. \quad H(s) = \frac{1}{s+a}$$

$$s \rightarrow \infty \quad Lt = \frac{(1/s)}{1 + (a/s)} = \frac{0}{1} = 0$$

$$s \rightarrow 0 \quad Lt = \frac{1}{a} \rightarrow \text{constant}$$

$$\therefore H(s) = \frac{1}{s+a} \rightarrow \text{LPF}$$

Cascaded LPF

$$= \frac{1}{(s+a)(s+a)} = \frac{1}{s^2 + 2sa + a^2}$$

$$\equiv \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

When $a=1$

$$2\delta\omega_n = 2$$

$$\delta = 1 \Rightarrow \text{critically stable.}$$

74. Synthesis of L-C Immittance Function Properties:

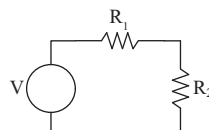
1. The impedance $\{Z_{LC}(s)\}$ or the Admittance $\{Y_{LC}(s)\}$ of these function are odd to even or even to odd polynomials.
2. The poles and zeros are simple and lie on the $j\omega$ axis.
3. The Poles and zeros and inter lace on the $j\omega$ axis.
4. The highest power of numerator $N(s)$ and denominator $D(s)$ must differ by unity, the lowest power also differ by unity.
5. There must be either a zero or pole at the origin and infinity.

76. Maximum current flow at resonance i.e., $Z_{in} = [V/R]$ at $\omega = \omega_0$

$$77. \quad \begin{vmatrix} A & B \\ C & D \end{vmatrix} = \begin{vmatrix} A' & B' \\ C' & D' \end{vmatrix} \begin{vmatrix} A'' & B'' \\ C'' & D'' \end{vmatrix}$$

78. Real part of pole and zero must be negative or zero Since RC network is used they must be simple.

79.



$$\bullet \quad V_{R1} = \frac{V}{R_1 + R_2} \times R_1; \quad V_{R2} = \frac{V}{R_1 + R_2} \times R_2$$

If R_1 and R_2 Double

$$\bullet \quad V_{2R1} = \frac{V}{2(R_1 + R_2)} \times 2R_1 = V_{R1}$$

$$\bullet \quad V_{2R2} = \frac{V}{2(R_1 + R_2)} \times 2R_2 = V_{R2}$$

Hence voltage across resistor does not change.

81. Under steady state condition $C \rightarrow$ open circuit
82. The nodal method of circuit analysis is based on KCL and Ohm's law
83. Superposition theorem is not applicable to network containing non-linear elements.
84. The first and the last critical frequency of an RC-driving point impedance function must respectively be a pole and a zero

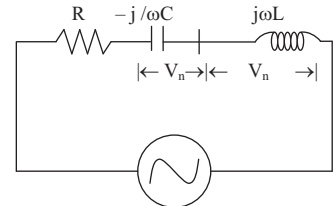
85.



RL – driving point admittance or

RC – driving point impedance

92.



At reason $I = [V/R]$

$$V_c = \frac{V}{R} \frac{j}{\omega C} = \frac{V}{R\omega C} \angle -90^\circ$$

It may be $R\omega C < 1$.

Then $|V_c| > V$

95. It is used for only linear network

$$96. \quad Z(s) = 1 + \frac{s+1}{s^2 + s + 1} = 1 + \frac{1}{s+1}$$

$$Z_1(s) = 1 \Rightarrow R_1 = 1 \Omega$$

$$Y_2(s) = s \Rightarrow C = 1 F$$

$$Z_3(s) = s+1$$

$$\Rightarrow L_3 = 1 H, \quad R_3 = 1 \Omega$$

Thus $Z(s)$ is an R-L-C network.

97. At $f = 100 \text{ Hz}$

$$X_L = 2\pi fL$$

$$= 2\pi \cdot 100 \cdot L = 50 \Omega$$

$$L = \frac{50}{100 \times 2\pi} H$$

$$= \frac{1}{4\pi} H$$

At $f = 500 \text{ Hz}$ resonance

$$X_L = 5 \times 50 = 250 \Omega$$

At resonance $X_L = X_C$ and $Z_m = R$

$$I = \frac{V}{R} = \frac{100}{10} = 10 A$$

$$V_C = 250 \times 10 = 2500 V$$

98. $H(s) = LT$ (impulse response)

$$= \frac{2}{(s+3)^2 + 2^2} = \frac{2}{s^2 + 6s + 13}$$

99. $H(s) = \frac{1}{s+1}$

$$H(j\omega) = \frac{1}{1+j\omega} = \frac{1}{\sqrt{2}} \angle -45^\circ$$

$H(s) \cdot R(s)$ result as change output by $(1/\sqrt{2})$ in magnitude and phase shift by $(-\pi/4)$

Therefore, $\cos t$ when Pass through the function $\frac{1}{s+1}$, it change to $\frac{1}{\sqrt{2}} \cos\left(t - \frac{\pi}{4}\right)$

Another method

$$H(s) = \frac{1}{s+1} ; R(s) = \frac{s}{s^2+1}$$

$$C(s) = \frac{s}{(s+1)(s^2+1)}$$

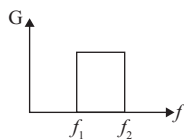
$$C(t) = LT^{-1} \left[\frac{s}{(s+1)(s^2+1)} \right]$$

$$c_{ss} = L t c(t)$$

$$= Lt \left[\frac{1}{\sqrt{2}} \cos\left(t - \frac{\pi}{4}\right) + \frac{1}{2} e^{-t} \right]$$

$$= \frac{1}{\sqrt{2}} \cos\left(t - \frac{\pi}{4}\right)$$

100. $G(s) = \frac{V_2(s)}{V_1(s)} = \frac{10s}{s^2 + 10s + 100}$



For $s \rightarrow 0$, $G(s) = 0$

and for $s \rightarrow \infty$, $G(s) = 0$

It mean it is BPF.

LEVEL 2

1. $\frac{V_1}{V_2} = \frac{C_2}{C_1} = 2$

But $V_1 + V_2 = 90$

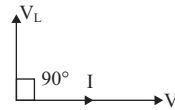
When capacitors are in parallel charge on each

$$= C_1 V_1 = C_2 V_2 = 1200 \mu C$$

$$V(C_1 + C_2) = 1200 \mu C = 2400 \mu C$$

$$V = \frac{2400}{60} = 40 V$$

7. Since $X_L = X_C = 20 \Omega$ which cancels each other, the circuit is purely-resistive and the current is in phase with the applied voltage. The voltage across the inductor leads the supply voltage by 90°



$$\text{Since } \bar{I} = \frac{100 \angle 0^\circ}{[(10 + j(20 - 20))]} = 10 \angle 0^\circ$$

$$\bar{V}_L = j\omega L \bar{I} = 20 \times 10 \angle 90^\circ = 200 \angle 90^\circ$$

8. (1) **Star-connected load**

$$V_{Rn} = V_m \cos \omega t$$

$$V_{Yn} = V_m \cos(\omega t - 120^\circ)$$

$$V_{Bn} = V_m \cos(\omega t + 120^\circ)$$

These are the voltage across the impedance or loads of respective phase.

$$I_R = I_m \cos \omega t$$

$$I_Y = I_m \cos(\omega t - 120^\circ)$$

$$V_B = I_m \cos(\omega t + 120^\circ)$$

These are the current through the impedance of the load in respective phase

$$\text{Line voltage are } V_{RY} = V_{Rn} - V_{Yn}$$

$$= \sqrt{3} V_m \cos(\omega t + 30^\circ)$$

Similarly, we can express V_{YB} and V_{BR} . Since load is star-connected, the currents given above are the line currents as well, and see that the line current I_R lags the line voltage V_{RY} by 30°

(2) **Delta-connected load**

$$\text{Let } V_{RY} = V_m \cos \omega t$$

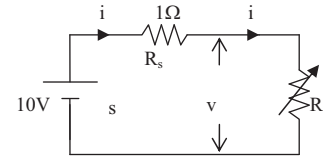
$$\text{Then } I_{RY} = I_m \cos \omega t$$

$$V_{BR} = V_m \cos(\omega t + 120^\circ)$$

$$\text{and } V_{BR} = I_m \cos(\omega t + 120^\circ)$$

$$I_R = I_{RY} I_{BR} = \sqrt{3} I_m \cos(\sqrt{3} t - 30^\circ)$$

9.



KVL in loop

$$-10 + 1 \cdot i + v = 0$$

Voltage across the non linear resistor

$$v = 10 - 1 \cdot i$$

$$7i = v^2 + 2v$$

$$= (10 - i)^2 + 2(10 - i)$$

$$= 100 + i^2 - 20i + 20 - 2i$$

$$\text{or } i^2 - 29i + 120 = 0$$

$$\therefore i = \frac{29 \pm \sqrt{(29)^2 - 4 \times 120}}{2}$$

$$= \frac{29 \pm \sqrt{841 - 480}}{2}$$

$$= 29 \pm \sqrt{361} = \frac{29 \pm 19}{2} = \frac{10}{2}$$

$$\text{or } \frac{28}{2} = 5 \text{ or } 24$$

10.

Symmetrical Network	Reciprocal Network
1. $Z_{11} = Z_{22}$	1. $Z_{12} = Z_{21}$
2. $Y_{11} = Y_{22}$	2. $Y_{12} = Y_{21}$
3. $A = D$	3. $\begin{vmatrix} A & B \\ C & D \end{vmatrix} = 1$ $\Rightarrow AD - BC = 1$
4. $a = d$	4. $\begin{vmatrix} a & b \\ c & d \end{vmatrix} = 1$ $\Rightarrow ad - bc = 1$
5. $\begin{vmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{vmatrix} = 1$	5. $h_{12} = -h_{21}$
6. $\begin{vmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{vmatrix} = 1$	6. $g_{12} = -g_{21}$

11. Voltage across capacitor

$$V_c = V_s (1 - e^{-t/RC})$$

$$= 10(1 - e^{-2/2})$$

$$= 6.32 V$$

12. $i = 2u(t-1)$

$$V_L = L \frac{di}{dt}$$

$$= 100 \times 10^{-3} \times \delta(t-1) = 0.2 \delta(t-1)$$

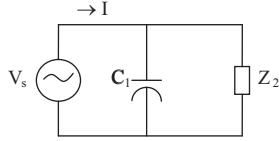
13. Wattmeter measure the average power

$$p = v i = (2 + 3 \sin 2\omega t)(1 + 2 \sin \omega t)$$

$$= 2 + 3 \sin 2\omega t + 4 \sin \omega t + 6 \sin 2\omega t \sin \omega t$$

$$P_{av} = 2 \text{ W}$$

- 14.



$$Z_2 = 1 + j$$

$$v = \cos 2t; \quad i = \cos 2t$$

$$\omega = 2$$

Since there is no difference in voltage and current phase difference, hence impedance must be purely resistive. It mean j term must be equal

$$\frac{-j}{\omega_c} = j$$

$$C = \frac{1}{\omega} = \frac{1}{2}$$

$$C = 0.25 \text{ F}$$

15. Load power with equal load $P_1 = \frac{3V_{ph}^2}{R}$

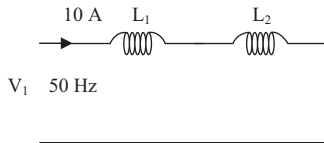
Load power with one arm open

$$P_2 = \frac{V_L^2}{2R} = 3 \frac{V_{ph}^2}{2R} = \frac{P_1}{2}$$

∴ Percentage reduction in load

$$\frac{P_1 - P_2}{P} = \frac{P_1 - \frac{P_1}{2}}{P_1} = 50\%$$

- 16.



$$V = 10(2L + 2M)\omega$$

Where terminal of coil reversed

$$V = 8(2L - 2M)\omega$$

$$\frac{10(2L + 2M)}{8(2L - 2M)} = 1$$

$$20L + 20M = 16L - 16MM$$

$$M^2 = \frac{-1}{9}L$$

$$M^2 = K_{L1}^2 L_2$$

$$K^2 = \frac{L^2}{81LX_L}$$

$$\Rightarrow K = \frac{1}{9}$$

26. From super position theorem

$$I_V = \frac{13}{1.5} = 2A$$

$$I_I = \frac{6}{3} \times I = 2A$$

27. Time Constant,

$$T = \frac{L}{R} = \frac{I^2 L}{I^2 R} = \frac{2 \frac{1}{2} I^2 L}{I^2 R}$$

$$\text{Thus, } T = \frac{2 \times 1000}{2000} = 1$$

28. If $V = V_m \sin \omega t$

$$Z = \sqrt{R^2 + L^2 \omega^2} \quad \text{and} \quad \phi = \tan^{-1} \frac{L\omega}{R}$$

Then

$$i(t) = \frac{V_m}{Z} \left[\sin(\omega t - \phi) - \sin(\omega t_o - \phi) e^{-(t-t_o)/T} \right]$$

Where t_o is the instant of switching

For no transient $\omega_o t = \phi$ or $\theta = \phi$
or $\theta - \phi = 0$

29. Current at response $= \frac{200}{5} = 40 \text{ A}$

30. When two coils are connected in series, the effective inductance is

$$L = L_1 + L_2 \pm 2M$$

$$\text{Thus, } L_1 + L_2 + 2M = 16$$

$$L_1 + L_2 - 2M = 8$$

31. The turns ratio has nothing to do with the coefficient of coupling

$$\frac{L_1}{L_2} = \left(\frac{N_1}{N_2} \right)^2$$

$$\text{Since } \frac{L_1}{L_2} = 1, \quad \frac{N_1}{N_2} = 1$$

33. $\frac{N_1^2}{N_2^2} = \frac{L_1}{L_2}$

• On doubling the number of turns the inductance becomes four times as inductance is proportional to the number of turns squared and resistance is only doubled since time constant is L/R i, the new time constant become

$$\frac{4L}{2R} = 2T$$

34. The impedance $= \frac{E_{rms}}{I_{rms}} = \frac{E_{peak}}{I_{peak}}$

$$\text{Or, } Z = 110/5 \text{ ohm} = 22 \text{ ohm}$$

35. $\Delta E = mc^2 - m_o c^2 = \frac{m_o c^2}{\sqrt{1 - v^2/c^2}} - m_o c^2$

$$= m_o c^2 \left[\frac{1}{\sqrt{1 - v^2/c^2}} - 1 \right]$$

$$= 0.51 \text{ MeV} = \left[\frac{1}{\sqrt{1 - 0.36}} - 1 \right]$$

$$= \frac{0.51}{4} \text{ MeV} = 0.13 \text{ MeV}$$

36. $V_{oc} = 100V, I_{sc} = 5A$

$$\therefore R_s = \frac{V_{oc}}{I_{sh}} = 20\Omega$$

$$I_L = \frac{V_{oc}}{R_s + R} = \frac{100}{20 + 80} = 1A$$

37. Number of nodes = 10

Number of different node pair voltages

$$= C_2^{10} = \frac{10!}{2!8!} = 45$$

and No of KCL equation $= n - 1 = 10 - 1 = 9$

38. For series network the z -parameter are added up. $Z = Z_1 + Z_2$

39. The impedance becomes resistive at resonance frequency

$$\omega = \frac{1}{\sqrt{LC}}$$

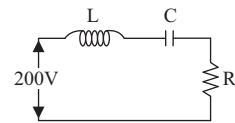
$$= \frac{1}{\sqrt{(1/16) \times 1}} = 4 \text{ rad/sec};$$

40. For $s = 0$, output has some value

For $s = \infty$, output is zero.

Hence is low pass filter.

- 41.



$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= R : (\text{since } |X_L| = |X_C|)$$

$$\therefore I = \frac{V}{R} = \frac{200}{10} = 20A$$

$$V_c = -jIX_c = 400 \angle -90^\circ V$$

42. $v(t) = (1 + e^{-t/\tau})u(t)$

$$\text{or, } V(s) = \frac{1}{s} + \frac{1}{s + 1/\tau}$$

$$Z(s) = C + R \parallel C$$

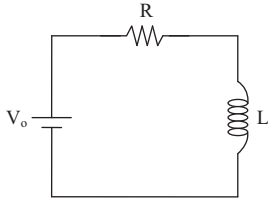
i.e., network consist of 1 R and 2 C.

43. Characteristic impedance

$$Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

For distortion less transmission line $R/L = G/C$

44.



$$V_L(t) = V_0 e^{-t/\tau}$$

Where $\tau = L/R$

$$V_R(t) = V_0 (1 - e^{-t/\tau})$$

For $V_L(t) = V_R(t)$

$$V_0 e^{-t/\tau} = V_0 (1 - e^{-t/\tau})$$

$$\text{or, } e^{-t/\tau} = [1/2]$$

Therefore, $t = \tau \ln 2$

45. From symmetry property

If $x(t) \leftrightarrow X(f)$

Then $X(t) \leftrightarrow x(-f)$

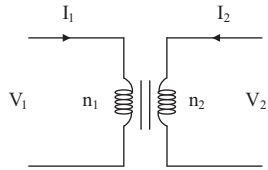
$$\therefore \delta(-f) = \delta(f) \leftrightarrow 1$$

47. The number of edges $= C_2 = \frac{n(n-1)}{2}$

48. 2 port n/w is reciprocal if,

$$AD - BC = 1, Z_{12} = Z_{21}, Y_{12} = Y_{21}, \\ h_{12} = -h_{21}, g_{12} = -g_{21}$$

49.



$$n = \frac{n_1}{n_2}$$

For ideal transformer, $\frac{V_1}{V_2} = n, \frac{I_1}{I_2} = -\frac{1}{n}$

$$A = \frac{V_1}{V_2} = n \quad ; \quad B = \frac{V_1}{I_2} = 0;$$

$$C = \frac{I_1}{V_2} = 0 \quad ; \quad D = \frac{I_1}{I_2} = \frac{1}{n}$$

50. $V_c = \frac{1}{C} \int i(t) dt$

$$V_c(s) = I(s) \times \frac{1}{sC} = \frac{1}{s} \times \frac{1}{sC} = \frac{1}{s^2 C}$$

$$\therefore V_c(t) = \frac{1}{C} r(t) \text{ i.e. ramp function}$$

51. Current in the circuit,

$$I = \frac{250}{\sqrt{(\omega L)^2 + R^2}} \sin(\omega t + \alpha)$$

Voltage across the inductance, $V_2 = (L di/dt)$

$$V_2 = \frac{250 L \omega \cos(\omega t + \alpha)}{\sqrt{[(L\omega)^2 + R^2]}}$$

$$\therefore |V_2| = \frac{250 L \omega}{\sqrt{[(L\omega)^2 + R^2]}}$$

$$\text{or, } 200 = \frac{250 L \omega \sin(\omega t + \alpha)}{\sqrt{[(400L)^2 + (100)^2]}}$$

$$\text{or } 250000L^2 = 160000L^2 + (10000)$$

$$\therefore L = (1/3) \text{ H}$$

$$\text{Not } \cos^2 \omega t = 1$$

52. When the coefficient of coupling is less than unity, parts of L_1 and L_2 do not take in mutual induction. These parts are known as leakage inductance of primary and secondary respectively.

$$K = \frac{M}{\sqrt{L_1 L_2}} = \frac{3}{\sqrt{9 \times 4}}$$

Primary leakage inductance $= L_1(1 - K)$
 $= 9(1 - 0.5) = 4.54$

Secondary leakage inductance $= L_2(1 - K)$
 $= 4(1 - 0.5) = 2$

53. The heat dissipated is maximum when $R = r = 40 \text{ ohm}$

$$\text{Thus, } I = [24/(4 + 4)] = 3 \text{ A}$$

Thus, the current will be $[I/2] = 1.5$ when the total resistance, $RT = [24/15] = 16 \text{ ohm}$

$$\text{Hence, } R = R_T - r = 12 \text{ ohms}$$

54. $Q = [f \Delta f]$

$$\text{Or } \Delta f = [f/Q] = [10^6/100] \\ = 10 \text{ KHz}$$

56. $\frac{s^2 + 3s + 1}{5(s^2 + 1)}$ is not a positive real function

57. Properties of L-C Immittance Function

1. The impedance $\{Z_{LC}(s)\}$ or the Admittance $\{Y_{LC}(s)\}$ of these function are odd to even or even to odd polynomials
2. The poles and zeros are simple and lie on the $j\omega$ axis
3. The Poles and zeros and inter lace on the $j\omega$ axis
4. The highest power of numerator $N(s)$ and denominator $D(s)$ must differ by unity, the lowest power also differ by unity
5. There must be either a zero or pole at the origin and infinity

58. If $F(s) = \frac{P(s)}{Q(s)}$, then for $F(s)$ to be

positive real, $P(s) + Q(s)$ must be Hurwitz. It satisfy only when

$$1 < K_1 < 2 \quad ; \quad 2 < K_2 < 3 \quad ; \quad 3 < K_3 < 4$$

$$\text{i.e. } |K_1 K_2 K_3| < 24.$$

$$59. X(s) = \frac{7s + 10}{s(s + 2)}$$

Initial value $x(0) = \lim_{s \rightarrow \infty} sX(s)$

$$= \frac{s(7s + 10)}{s(s + 1)} \bigg|_{s \rightarrow \infty} = \frac{(7s + 10)}{(s + 2)} \bigg|_{s \rightarrow \infty}$$

$$= \frac{7s + 10}{s + 2} \bigg|_{s \rightarrow \infty} = \frac{7}{1} = 7$$

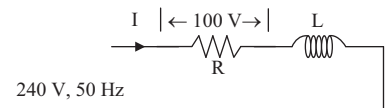
Final value $x(\infty) = \lim_{s \rightarrow 0} sX(s)$

$$= s \times \frac{7s + 10}{s(s + 2)} \bigg|_{s=0}$$

$$= \frac{7s + 10}{s + 2} \bigg|_{s=0} = \frac{10}{2} = 5$$

61. Gain of 12 db for double frequency
 i.e., 12 db/octave (double frequency)
 6 db/octave = 20 db/decade
 the 12 db/octave = 40 db/decade

64.



$$\text{Power dissipated} = I^2 R = 300 \text{ W}$$

$$\text{Voltage across } R = IR = 100 \text{ V}$$

$$\text{Current } I = \frac{I^2 R}{IR} = \frac{300}{100} = 3 \text{ A}$$

$$\text{Resistance } R = \frac{V}{I} = \frac{100}{3}$$

$$V^2 = V_R^2 + V_L^2$$

$$V_L^2 = (240)^2 - (100)^2 \\ = 57600 - 10000 \\ = 47600$$

$$V_L = 218.16$$

$$= X_L I$$

$$\bullet X_L = \frac{V_L}{I} = \frac{218.16}{3} = 72.72$$

• For unity power factor

$$\bullet X_L = \omega L = \frac{1}{\omega C} = 72.72$$

$$\bullet \omega_c = \frac{1}{72.72}$$

$$\bullet C = \frac{1}{\omega \times 72.72} = \frac{1}{2\pi f \times 72.72}$$

$$\bullet = \frac{1}{2 \times 3.14 \times 50 \times 72.72} = 43.7 \mu F$$

65. For a symmetrical two-port network,
 $A = D = 3 \Omega$

And for a reciprocal/bilateral two-port network, $AD - BC = 1$

$$\Rightarrow 3 \times 3 - 1 \times C = 1$$

$$\Rightarrow C = 8$$

66. Number of loop equations = Number of KVL equation in a circuit = $b - n + 1 = 10 - 7 + 1 = 4$

$$67. \frac{d^2 i}{dt^2} + i = v$$

Where, $v = A e^{2t}$

$$\text{Then, } \frac{d^2 i}{dt^2} + i = A e^{2t}$$

Take Laplace transform

$$s^2 I(s) + I(s) = \frac{A}{s-2}$$

$$I(s) = \frac{(s^2 + 1)}{s-2} = \frac{A}{s-2}$$

$$I(s) = \frac{A}{(s^2 + 1)(s-2)}$$

The two pole $\frac{1}{s^2 + 1} \rightarrow$ Gives sin function

$\frac{1}{(s-2)} \rightarrow$ Gives exponential rising function which will dominate the solution as it tends to un stabilize the system i.e., e^{2t}

68. Ramp response = $t + e^{-t}$

$$\text{Step response} = \frac{d}{dt} (\text{ramp response})$$

$$= \frac{d}{dt} (t + e^{-t}) = 1 - e^{-t}$$

69. For maximum and minima

$$\frac{di(t)}{dt} = 0$$

$$\text{or } = -\alpha k t e^{-\alpha t} + k e^{-\alpha t} = 0$$

$$\text{or } K e^{-\alpha t} (1 - \alpha t) = 0$$

$$\text{or } 1 - \alpha t = 0$$

$$\text{or } t = \frac{1}{\alpha}$$

70. h-parameter

$$V_1 = h_{11} I_1 + h_{12} V_2$$

$$I_2 = h_{21} I_1 + h_{22} V_2$$

Z-parameter

$$V_1 = Z_{11} I_1 + Z_{12} I_2$$

$$V_2 = Z_{21} I_1 + Z_{22} I_2$$

Y-parameter

$$I_1 = Y_{11} V_1 + Y_{12} V_2$$

$$I_2 = Y_{21} V_1 + Y_{22} V_2$$

From the above equation

$$h_{11} = \left. \frac{V_1}{I_1} \right|_{V_2=0}$$

$$Y_{11} = \left. \frac{I_1}{V_1} \right|_{V_2=0}$$

$$\Rightarrow \frac{1}{Y_{11}} = \left. \frac{V_1}{I_1} \right|_{V_2=0}$$

$$h_{22} = \left. \frac{I_2}{V_2} \right|_{I_1=0}$$

$$Z_{22} = \left. \frac{V_2}{I_2} \right|_{I_1=0}$$

$$\Rightarrow \frac{1}{Z_{22}} = \left. \frac{I_2}{V_2} \right|_{I_1=0}$$

$$\therefore h_{11} = \frac{1}{y_{11}} \text{ and } h_{22} = \frac{1}{Z_{22}}$$

$$71. Z(s) = \frac{s+2}{(s+3)} = \frac{V(s)}{I(s)}; V(s) = \frac{1}{s}$$

$$I(s) = \frac{V(s)}{Z(s)} = \frac{(1/s)}{(s+2)/(s+3)} = \frac{(s+3)}{s(s+2)}$$

$$= \frac{A}{s} + \frac{B}{s+2}$$

$$s+3 = A(s+2) + B(s)$$

$$= s(A+B) + 2A$$

Compare the coefficient

$$2A = 3 \Rightarrow A = \frac{3}{2}$$

$$A + B = 1 \Rightarrow B = 1 - A$$

$$= 1 - \frac{3}{2} = -\frac{1}{2}$$

$$I(s) = \frac{3/2}{s} - \frac{1/2}{s+2}$$

$$i(t) = \frac{3}{2} - \frac{1}{2} e^{-2t}$$

72. For maximum power transfer, load impedance is equal to complex conjugate of source impedance.

$$Z_L = Z_g^*$$

$$73. H(s) = LT 5u(t) = \frac{5}{s}$$

$$(R)s = LT(e^{-t}) = \frac{1}{s+1}$$

$$\text{Output } C(s) = H(s) \cdot R(s)$$

$$= \frac{5}{s} \cdot \frac{1}{(s+1)} = 5 \left[\frac{1}{s} - \frac{1}{s+1} \right]$$

$$\text{then } C(t) = LT^{-1}C(s) = 5[1 - e^{-t}]u(t)$$

74. Calculate $Y_m(j\omega)$. The impedance of the whole circuit is independent of frequency when imaginary $Y_m(j\omega) = 0$ which gives

$$R_L = R_C \text{ and } \omega = \frac{1}{\sqrt{LC}}$$

In other words, circuit is in resonance for

$$R_L = R_C \text{ and } \omega = \frac{1}{\sqrt{LC}} \text{ i.e., not for all the frequencies.}$$

Further, two branch currents will be in quadrature. When

$$\tan^{-1} \left(\frac{1}{\omega C R_C} \right) - \tan^{-1} \left(\frac{\omega L}{R} \right) = 90^\circ$$

$$\text{Which gives } R_L \cdot R_C = \frac{L}{C}$$

75. $i_3 = -i_1 - i_2$

$$= -10[\sin(400t + 60) + \sin(400t - 60)]$$

$$= -10[\sin 400t]$$

Second Method

$$i_3 = -(i_1 + i_2)$$

$$i_1 = 10 \sin(400t + 60^\circ) = 10 \cos(400t - 30^\circ)$$

$$= 10(0.866 - 0.5j)A$$

$$i_2 = 10 \sin(400t - 60^\circ) = 10 \cos(400t - 150^\circ)$$

$$= 10(-0.866 - 0.5j)A$$

$$i_3 = -10jA = \cos(400t - 90^\circ)$$

$$= -10 \sin(400t)A$$

$$76. Z(s) = \frac{5s}{s^2 + 0.5s + 100}$$

$$Y(s) = \frac{s^2 + 0.5s + 100}{5s}$$

$$= \frac{s}{5} + 0.1 + \frac{100}{5s}$$

$$= \frac{s}{5} + 0.1 + \frac{20}{s}$$

$$R = 10 \Omega, L = \frac{1}{20} H, C = \frac{1}{5} F$$

$$77. I(s) = \frac{V(s)}{Z(s)} = \frac{V(s)(s+\beta)}{s+\alpha}$$

$$V(s) = I(s) \cdot \left(\frac{s+\alpha}{s+\beta} \right)$$

$$\phi = \tan^{-1} \left(\frac{\omega}{\alpha} \right) - \tan^{-1} \left(\frac{\omega}{\beta} \right)$$

for $V(s)$ to lead $I(s)$, $\phi > 0$ or $\beta > \alpha$

$$78. \frac{V(s)}{I(s)} = \frac{s+3}{(s+2)^2}$$

$$I(s) = \frac{1}{s}$$

$$V(s) = \frac{(s+3)}{s(s+2)^2}$$

$$V(0) = \lim_{s \rightarrow \infty} s V(s) = \lim_{s \rightarrow \infty} \frac{s(s+3)}{s(s+2)^2} = 0$$

$$V(\infty) = \lim_{s \rightarrow 0} s V(s) = \lim_{s \rightarrow 0} \frac{s(s+3)}{s(s+2)^2} = \frac{3}{4}$$

$$79. I(s) = \frac{k}{s^2 + 6s + 9} = \frac{k}{(s+3)^2}$$

$$= \frac{k_1}{s+3} + \frac{k_2}{(s+3)^2}$$

$$\text{or } I(t) = (k_1 + k_2 t) \cdot e^{-3t}$$

80. For max power transfer $Z_L = Z_Z^*$ if not then at least magnitude must be equal i.e.

$$R_L = \sqrt{8^2 + 6^2} = \sqrt{64 + 36} = 10$$

81. For balance connection

$$Z_A = 3 Z_Y$$

$$\text{Per phase } Z_Y = \frac{Z_A}{3} = \frac{9 \angle 30^\circ}{3} = 3 \angle 30^\circ \Omega$$

82. Damped frequency

$$\omega_d = \sqrt{\omega_0^2 - \alpha^2}; \text{ where } \alpha = \frac{B.W}{2}$$

$$\therefore \omega_0^2 = \omega_d^2 + \alpha^2$$

$$\omega_0^2 = (\sqrt{8})^2 + \left(\frac{2}{2}\right)^2 = 9$$

$$\text{or, } \omega_0 = 3 \text{ rad/s}$$

$$83. V_R = \sqrt{15^2 - 9^2} = \sqrt{255 - 81} = \sqrt{144} = 12 \text{ V}$$

$$V_L = \sqrt{20^2 - 12^2} = \sqrt{400 - 144} = \sqrt{256} = 16 \text{ V}$$

$$|V_L \sim V_C| = 9$$

$$V_C = 7 \text{ V or } 25 \text{ V}$$

$$84. V_{AN} = V_{AB} + V_{BN} = 400 + 200 \angle -120^\circ = (300 - j100\sqrt{3})$$

$$|V_{AN}| = 200\sqrt{3} \text{ V}$$

85. Forster second form are realized for $X(s)$

$$\text{Give, } Z(s) = \frac{(s+3)(s+5)}{(s+4)(s+6)} = \frac{s^2 + 8s + 15}{s^2 + 10s + 25}$$

$$\text{Then } Y(s) = \frac{s^2 + 10s + 24}{s^2 + 8s + 15}$$

$$Y(s) = 1 + \frac{(2s+9)}{(s+3)(s+5)}$$

$$\downarrow \quad \downarrow$$

$$Y_1 + Y_2$$

$$Y_2 = \frac{(2s+9)}{(s+3)(s+5)} = \frac{A}{s+3} + \frac{B}{s+5}$$

$$(2s+9) = A(s+5) + B(s+3)$$

$$= s(A+B) + 5A + 3B$$

Comparing coefficient

$$A+B=2$$

$$5A+3B=9$$

$$3A+3B=6$$

$$\text{or } 2A=3$$

$$A = \frac{3}{2}$$

$$\text{Then } B = 2 - \frac{3}{2} = \frac{1}{2}$$

$$Y_2 = \frac{3/2}{s+3} + \frac{1/2}{s+5}$$

$$\downarrow \quad \downarrow$$

$$Y_2' + Y_2''$$

$$Y_2' = \frac{3/2}{s+3}$$

$$Z_2' = \frac{s+3}{3/2} = \frac{2s}{3} + 2$$

$$L_2' = \frac{2}{H} \text{ and } R_2' = 2 \Omega \text{ and}$$

$$Y_2'' = \frac{1/2}{s+5}$$

$$\Rightarrow Z_2'' = \frac{s+5}{2} = 2s + 10$$

$$L_2'' = 2H \text{ and } R_2'' = 10 \Omega$$

$$= 1 + \frac{1}{\frac{2s}{3} + 2} + \frac{1}{2(s+5)}$$

$$\text{Which given, } R = 2 \Omega, L = \frac{2}{3} H$$

86. Initial voltage at C of 3 volts.

$$\text{Overall response, } v'(t) = V_o(t) + v(t)$$

$$= 1 - e^{-3t} + 3e^{-3t} = 1 + 2e^{-3t}$$

87. At $\omega < \omega_o$, $X_C > X_L$ as current is same in series voltage across capacitor $I \cdot X_C$ is maximum.

88. Properties of LC function

1. The impedance $\{Z_{LC}(s)\}$ or the Admittance $\{Y_{LC}(s)\}$ of these function are odd to even or even to odd polynomials.

2. The poles and zeros are simple and lie on the $j\omega$ axis.

3. The poles and zeros and inter lace on the $j\omega$ axis.

4. The highest power of numerator $N(s)$ and denominator $D(s)$ must differ by unity, the lowest power also differ by unity.

5. There must be either a zero or pole at the origin and infinity.

89. Under steady state condition capacitor C_1 and C_2 will behave as open circuit for dc current I after being charged and inductor is short circuit.

90. For short circuit case, use the Y-parameter equation and solving it.

$$\begin{aligned} I_1 &= Y_{11}V_1 + Y_{12}V_2 \\ I_1 &= Y_{21}V_1 + Y_{22}V_2 \end{aligned} \quad (1)$$

$$\text{Given } V_1 = 10 \text{ V, } I_2 = 1 \text{ A}$$

$$\text{Then, } Y_{21} = \left. \frac{I_2}{V_1} \right|_{V_2=0} = \frac{1}{10}$$

$$\text{Given, } V_2 = 100 \text{ V, and } V_1 = 0, \text{ Then } I_1 = ?$$

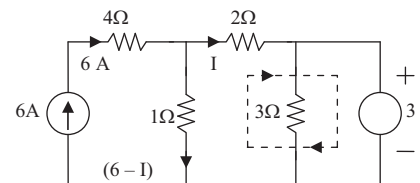
$$\text{Then, form equation (1)}$$

$$I_1 = Y_{12} \cdot V_2$$

$$= Y_{21} \cdot V_2 = \frac{1}{10} \cdot 100 = 10$$

91. Short-circuit the voltage source and open-circuit the current source then $R_{th} = 2 \Omega$

92.



Using KVL in the second loop

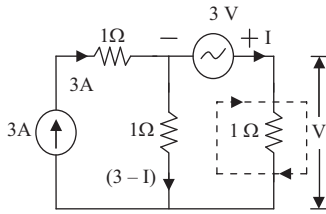
$$2I + 3 - (6 - I) = 0$$

$$\Rightarrow 2I + I = 6 - 3$$

$$\Rightarrow 3I = 3$$

$$\Rightarrow I = 1 \text{ A}$$

93.



KVL around the drawn loop
 $-3 + I - (3 - 1) = 0$

$$\Rightarrow 2i = 6$$

$$\Rightarrow I = 3A$$

$$\text{then } V = 1 \times 3 = 3 \text{ V}$$

$$94. \quad Z(s) = \frac{4s^4 + 7s^2 + 1}{s(2s^2 + 3)}$$

$$Z(s) = \frac{4s^4 + 7s^2 + 1}{2s^3 + 3s}$$

$$= 2s + \frac{s+1}{2s^3+3}$$

↓

$$Z_1$$

$$Z_1 = 2s \Rightarrow L_1 = 2$$

Another method:

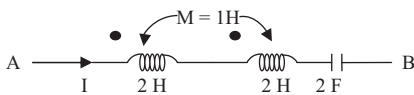
Present diagram represent the cauer's method representation which can be obtained by continued fractional expansion.

95. Compute $Z(j\omega)$ and put imaginary part equal to zero.

For resonance the condition is

$$R^2 = \frac{L}{C} \Rightarrow C = \frac{L}{R^2} = \frac{1}{16} F$$

96.



As per dot conversion flux it additive

$$\therefore L_{eq} = L_1 + L_2 + 2M = 2 + 2 + 2 \times 1 = 6 \text{ H}$$

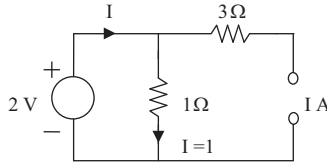
$$\therefore f = \frac{1}{2\pi\sqrt{L_{eq}C}} = \frac{1}{2\pi\sqrt{6 \times 2}} = \frac{1}{4\pi\sqrt{3}} \text{ Hz}$$

97. Voltage source in series with constant current source will behave like short circuit

Current through 120 Ω

$$i = \frac{25}{7} - \frac{4}{7} = 3 \text{ A}$$

99. For considering voltage source open circuit the current source



Current in $1\Omega = 2A$

$\therefore$ current delivered by $2V$ source = $1A$

$\therefore$ power delivered by $2V$ source
 $= 2 \times 1 = 2W$

100. Y para meter

$$I_1 = Y_{11} V_1 + Y_{12} V_2$$

$$I_2 = Y_{21} V_1 + Y_{22} V_2$$

Form the given circuit

$$V_1 = I_1 R_1$$

$$I_1 = V_1 R_1^{-1} + V_2 \cdot 0$$

$$I_2 = V_1 \cdot 0 + V_2 \cdot 0$$

$$\text{then } [Y] = \begin{bmatrix} R_1^{-1} & 0 \\ 0 & 0 \end{bmatrix}$$

LEVEL 3

$$1. \quad H(s) = \frac{K(S-1-j)(S-1+j)(S-1)}{(s+1-j)(s+1+j)(S+1)}$$

$$= \frac{K(S^2 - 2s + 1)(S-1)}{(S^2 + 2s + 1)(S+1)}$$

$$= \frac{K(S-1)^2(S-1)}{(s+1)^2(S+1)} = \frac{K(S-1)^2}{(S+1)^2}$$

$$= \frac{K(\tan^{-1}[1/-1])^2}{\tan[1/1]^2} = K$$

$\angle$ constant angle

All pass filter having constant magnitude.

* Since all pole have corresponding zero in the right hand side of s -plane. Hence it is a all pass filter. This is the characteristic of all pass filter

$$2. \quad H(s) = R_2 \parallel [1/SC_2]$$

$$R_1 \parallel [1/SC_1] + R_2 \parallel [1/SC_2]$$

$$= \frac{[R_2/1 + SC_2 R_2]}{\frac{R_1}{1 + SC_1 R_1} + \frac{R_2}{1 + SC_2 R_2}}$$

But, $R_1 C_1 = R_2 C_2$

$$H(s) = [R_2/(R_1 + R_2)]$$

$$h(t) = LT^{-1} [H(s)]$$

$$= [R_2/(R_1 + R_2)] \delta(t)$$

$$3. \quad N_1 : Z = (1 + 2s) \parallel [2 + (1/s)] \parallel (1/s)$$

$$= \frac{(2s+1) \times (1+2s)}{\frac{s}{(2s+1)} \times 1 + 2s} \parallel [1/s]$$

$$= \frac{(2s+1) \times (1+2s)}{(2s+1) + (1+2s) \cdot s} \parallel [1/s]$$

$$= \frac{(2s+1)^2}{(2s+1) + s(1+2s)} \parallel [1/s]$$

$$= \frac{(2s+1)^2}{(2s+1) \times (s+1)} \parallel [1/s]$$

$$= \frac{(2s+1)}{(s+1)} \parallel [1/s]$$

$$N_2 : Z = [2s + 1] \parallel [2 + (1/s)]$$

$$= [(2s+1)/(s+1)]$$

$$N_3 : Z = [1/s] \parallel [1 + s(s+1)]$$

$$= [1/s] \parallel [(2s+1)/(s+1)]$$

$$N_4 : Z = [1/s] \parallel [2s + 1]$$

N_1 & N_3 are identical

4. Current and voltage follow the super position theorem. Since power is not a linear function it does not follow superposition.

$$V_1 \text{ alone } P = I^2 R$$

$$4 = I_1^2 R \quad ; \quad I_1 = [\sqrt{4/R}] = [2/\sqrt{R}]$$

$$I_2 \text{ alone } P = I^2 R$$

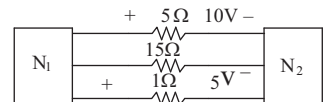
$$9 = I_2^2 R \quad ; \quad I_2 = [\sqrt{9/R}] = [3/\sqrt{R}]$$

$$\text{For, } V_1 \text{ \& } I_2 \quad ; \quad I = I_1 + I_2$$

$$= \frac{2}{\sqrt{R}} + \frac{3}{\sqrt{R}} = \frac{5}{\sqrt{R}}$$

$$P = I^2 R = [25/R] \times R = 25 \text{ Watt}$$

5. KCL for a cutset state that algebraic sum of the current entering or leaving a cut set is equal to zero



$$I_5 + I_{15} + I_1 = 0$$

$$\text{Or, } [10/5] + I_{15} + [5/1] = 0$$

$$I_{15} = -7A$$

$$V_{15} = -7 \times 15$$

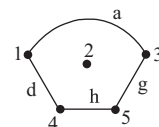
$$= -105 \text{ V}$$

6. KCL at Node

$$I_0 + i_1 + i_4 = 0$$

$$5 + 7 + i_4 = 0; \quad i_4 = -12$$

7. A tree should touch all the nodes of the graph

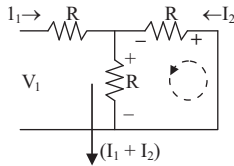


8. For h-parameter

$$V_1 = h_{11} I_1 + h_{12} V_2$$

$$I_2 = h_{21} I_1 + h_{22} V_2$$

$$h_{21} = \left. \frac{I_2}{I_1} \right|_{V_2=0}$$



For $V_2 = 0$, output is short circuited

$$R(I_1 + I_2) + RI_2 = 0 \text{ Or, } RI_1 + 2RI_2 = 0$$

$$\frac{I_2}{I_1} = -[1/2] = h_{21}$$

$$9. Z = \frac{(j2 \times -j6)(3+j4)}{(j2-j6) + (3+j4)} = \frac{36+j48}{3}$$

$$I = \frac{100 \times 3}{36+j48}$$

$$I_1 \text{ for } j4 = \left(\frac{100 \times 3}{36+j48} \right)$$

$$\times \frac{(j2 \times -j6)}{(j2-j6) + (3+j4)}$$

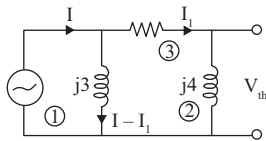
$$= \frac{100 \times 3}{36+j48} \times \frac{12}{3} = \frac{100 \times 12}{12(3+j4)}$$

$$V_L = \frac{100(j4)}{3+j4} \times \frac{3-j4}{3-j4} = \frac{100 \times j4(3-j4)}{25}$$

$$V_L = j16(3-j4)$$

Second Method

$$\therefore j2 \parallel -j6 = j3$$



From loop (1)

$$j3(I - I_1) = 100$$

$$j3I = 100 + j3I_1$$

From loop (2)

$$3I_1 + j4I_1 - j3(I - I_1) = 0$$

From (1),

$$(3+j4+j3)I_1 - (100+j3I_1) = 0$$

$$I_1 = \frac{100}{3+j4}$$

$$V_{th} = j4 \times \frac{100}{3+j4}$$

$$V_{th} = \frac{100(j4)(3-j4)}{(3+j4)(3-j4)}$$

$$V_{th} = j16(3-j4)$$

10. For maximum power transfer $Z_L = Z_S^*$

$$R_L = R_S$$

$$Z_S = (5 \parallel 20) + 4 = \frac{5 \times 20}{5+20} + 4$$

$$= \frac{100}{25} + 4 = 4 + 4 = 8$$

$$11. R_1 = \frac{R_{ab}R_{ac}}{R_{ab} + R_{bc} + R_{ca}} = \frac{5 \times 30}{50} = 3$$

$$R_2 = \frac{R_{ab} \cdot R_{bc}}{R_{ab} + R_{bc} + R_{ca}} = \frac{5 \times 15}{50} = \frac{3}{2} = 1.5$$

$$R_3 = \frac{R_{bc} \cdot R_{ac}}{R_{ab} + R_{bc} + R_{ca}} = \frac{5 \times 30}{50} = 9$$

12. $V_L = L [di/dt]$

$$= 1 \cdot [d/dt] [e^{at} + e^{bt}]$$

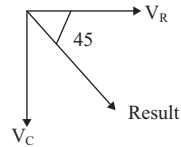
$$= a e^{at} + b e^{bt}$$

13. Apply the KVL between 0 and 10 V

$$1 + E + 5 + 10 = 0$$

$$E = -16 \text{ V}$$

14. Capacitor get charged with Rms voltage and it lag the main current, therefore voltage across capacitor is $3 + [4/\sqrt{2}] \sin [100t - (\pi/4)] \text{ V}$



$$15. Z_{in} = 4 + [4 \parallel 2 + 2]$$

$$= 4 + [4 \parallel 4] = 4 + 2 = 6$$

$$I = [12/6] = 2 \text{ A}$$

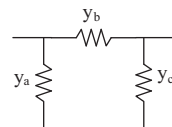
$$I_{4\Omega} = 1 \text{ A};$$

$$e_o = 4 \times 1 = 4 \text{ V}$$

$$16. I_1 = y_{11} V_1 + y_{12} V_2$$

$$I_2 = y_{21} V_1 + y_{22} V_2$$

NOTE: π type network

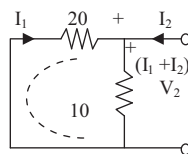


$$y_{11} = y_a + y_b$$

$$y_{22} = y_b + y_c$$

$$y_{12} = y_{21} = -y_b$$

Network is reciprocal



$$y_{12} = \left. \frac{I_1}{V_1} \right|_{V_2=0}$$

$$V_2 = 10 I_1 + 10 I_2 = 10 (I_1 + I_2)$$

$$V_2 = -20 I_1$$

$$y_{12} = [I_1/V_2] = -[1/20] = -0.05 \text{ moh}$$

$$17. i_2(t) = \frac{E_m \cos \omega t}{R_2 + \frac{1}{j\omega C_2}}$$

$$= E_m \angle 0 \frac{j\omega C}{1 + j\omega R_2 C}$$

$$= \frac{E_m \omega C}{\sqrt{1 + \omega^2 R_2^2 C^2}} \angle 90^\circ - \tan^{-1} \omega R_2 C$$

$$\text{At } \omega = 0 \Rightarrow i_2(t) = 0 \text{ and } \angle I_2 = 90^\circ$$

$$\text{At } \omega = \infty \Rightarrow i_2(t) = \frac{E_m}{R_2} \text{ and } \angle I_2 = 0^\circ$$

$$18. V_1 = Z_{11} I_1 + Z_{12} I_2$$

$$V_2 = Z_{21} I_1 + Z_{22} I_2$$

When $I_2 = 0$

$$E_1 = 6 I_1 - 10 E_1$$

$$\text{Or, } 11 E_1 = 6 I_1, Z_{11} = [V_1/I_1]$$

$$Z_{11} = [E_1/I_1] = [6/11] \Omega$$

$$E_2 = 4 I_1 - 10 E_1$$

$$= 4 I_1 - 10 [(6/11) I_1]$$

$$E_2 = \frac{44I_1 - 60I_1}{11} = \frac{-16I_1}{11}$$

$$Z_{21} = [E_2/I_1] = [-16/11] \Omega.$$

$$19. 20 = 5 I + [(V/5) + I] 5$$

$$= 5 I + (4 + 1) 5$$

$$20 = 5 I + 20 + 5I \quad ; \quad I = 0$$

$$\text{Power delivered} = [(20/5)^2] \times 5 = 4^2 \times 5 = 80 \text{ Watt}$$

20. Number of node $n = 5$

Number of branches $b = 8$

$$\text{Number of KCL equation} = (n - 1) = (5 - 1) = 4$$

$$\text{Number of KVL equation} = b - n + 1 = 8 - 5 + 1 = 4$$

21. Using KVL equation the loop

$$V(t) = R i(t) + L [di(t)/dt] + [1/c] \int i(t) dt$$

$$\sin t = 2 i(t) + 2 [di(t) dt] + \int i(t) dt$$

Differentiate the above equation

$$\cos t = 2 [di(t)/dt] + 2 [d^2 i(t) dt^2] + i(t)$$

22. Here the value of inductance is not given we can ignore it

$$I_1 = \frac{2 \cos 4t}{3} = 0.67 \cos 4t \text{ i.e., } \omega = 4$$

$$I_2 = \frac{-j\omega M}{R - [j/\omega C]} = \frac{-j \times 0.75 I_1}{3.92 - 2.56j}$$

$$= -\frac{j3 \times 0.67 \cos 4t}{3.92 - 2.56j} \times \frac{3.92 + 2.56j}{3.92 + 2.56j}$$

$$= (0.23 - 0.35j) \cos 4t$$

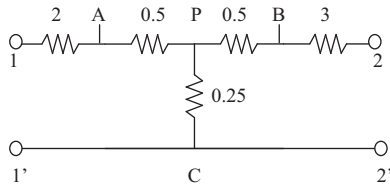
$$23. \quad Z(s) = \frac{K(s+3)}{(s+1+j)(s+1-j)}$$

$$= \frac{k(s+3)}{(s+1)^2 + 1}$$

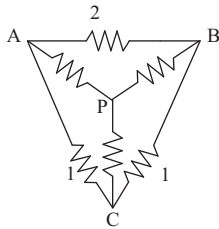
$$Z(o) = 3 = [3K/2]; \quad K = 2$$

$$Z(s) = \frac{2(s+3)}{(s+1)^2 + 1} = \frac{2(s+3)}{s^2 + 2s + 2}$$

24.



Convert the π into T configuration i.e. Δ into y



$$Z_{AP} = \frac{Z_{AB} \cdot Z_{AC}}{Z_{AB} + Z_{AC} + Z_{BC}} = \frac{2}{4} = 0.5$$

$$Z_{PB} = \frac{Z_{AB} \cdot Z_{BC}}{Z_{AB} + Z_{BC} + Z_{AC}} = \frac{2}{4} = 0.5$$

$$Z_{PC} = \frac{Z_{AC} \cdot Z_{BC}}{Z_{AB} + Z_{BC} + Z_{AC}} = \frac{1}{4} = 0.25$$

$$V_1 = 2.75 I_1 + 0.25 I_2$$

$$V_1 = Z_{11} I_1 + Z_{12} I_2$$

$$Z_{11} = 2.75 \text{ \& } Z_{12} = 0.25 \text{ \Omega}$$

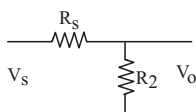
25. In we analyse the circuit at $\omega = 0$ and $\omega = \infty$, then we will be able to draw the frequency response

At $\omega = 0$

$C \rightarrow$ open circuit

$L \rightarrow$ Short circuit

Circuit look like

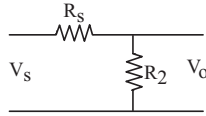


$$\frac{V_o}{V_s} = \frac{R_2}{R_2 + R_s} \text{ finite value}$$

At $\omega = \infty$

$C \rightarrow$ Short circuit

$L \rightarrow$ open circuit



$$\frac{V_o}{V_s} = -\frac{R_2}{R_s + R_2}$$

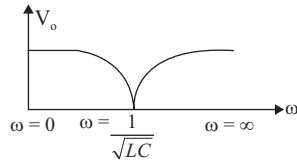
$$\text{At } \omega = \frac{1}{\sqrt{LC}}$$

Series LC circuit $\rightarrow$ minimum impedance
i.e. short circuit

Parallel LC circuit $\rightarrow$ maximum impedance
i.e. open circuit

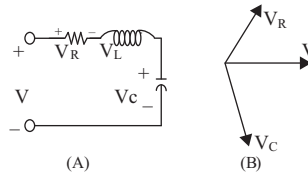
Then $V_o = 0$

The frequency response curve is given by

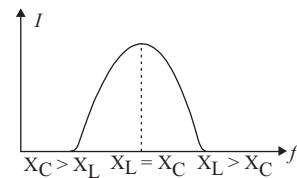
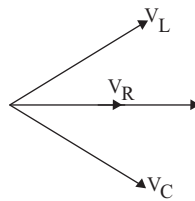


26. Reciprocity theorem hold good for linear network when voltage source is double current becomes double

27.



For a quick analysis, V_R in phase with I_R leads V_C by 90° and hence capacitive. A series resonant circuit is capacitive below resonant frequency.



When $X_C = X_L$, the series circuit resonates. In present case since $V_C > V_L$ in magnitude as shown by the figure then less than resonance become X_C us

is inversely proportional to frequency
 $X_C > X_L$ the frequency is going to be

$$28. \text{ Mutual inductance } M = K \sqrt{L_1 L_2}$$

$$= K \sqrt{(16)} = 4K$$

Total impedance $Z = 18 - j12 + j2 + j8 + j8K$

For series resonance $-12 + 2 + 8 + 8K = 0$

$$\therefore 8K = 2$$

$$K = 0.25$$

29. For maximum power transfer to the $2 \text{ \Omega}$ resistance,

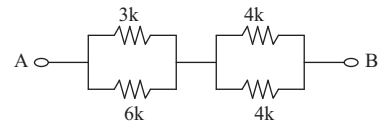
$$Z_{in} = \left(\frac{N_p}{N_s} \right)^2 Z_L$$

$$Z_{in} = 2 \left(\frac{N_p}{40} \right)^2 \text{ or } 4 \times (40)^2 = N_p^2$$

Hence number of turns is primary

$$N_p = \sqrt{(4 \times 40)^2} = 2 \times 40 = 80$$

30. The circuit is drawn below by shorting the voltage source and opening the Resistor R, we find the Z_{eq}



Taking the Thevenin's equivalent between points A, B

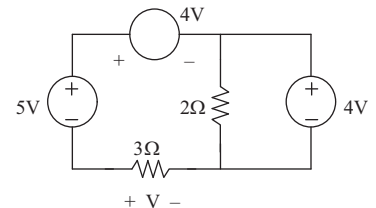
$$Z_{eq} = \left(\frac{6 \times 3}{6 + 3} + \frac{4 \times 4}{4 + 4} \right) = [18/9] + [16/8]$$

$$= 4 \text{ \Omega}$$

Load impedance should be equal to the complex conjugate of source impedance. When the above circuit is represented by thevenin's equivalent circuit.

For maximum power transfer $R = R_{eq} = 4 \text{ k}\Omega$

31. Voltage due to 4 V source is 4 V, because both resistor $2 \text{ \Omega}$ & $3 \text{ \Omega}$ are in parallel



Voltage due to 5 V and 4V; $2 \text{ \Omega}$ is measure by short circuiting $2 \text{ \Omega}$ Resistance.

p.d Across $3 \text{ \Omega}$ is -1 V

$$\text{Hence resultant} = (4 - 1) = 3 \text{ V}$$

32. Voltage V

(1) Due to 5 V, current source is open circuit

$\therefore$ no p.d

- (2) Due to 2 amp source p.d. = $2 \times 2 = 4 \text{ V}$

Resultant voltage $V = 0 + 4 \text{ V} = 4 \text{ Volt}$

33. Voltage

- (1) Due to 5 A, $V_1 = 0 \text{ V}$
 (2) Due to 10 V, $V_2 = +10 \text{ V}$
 $V = V_1 + V_2 = 0 + 10 = 10 \text{ V}$

34. Power absorbed by resistor

At $t = 0$,

$C \rightarrow$ Short circuit

$$I = \frac{V}{R} = \frac{10}{4}$$

$$P = I^2 R = \left(\frac{10}{4}\right)^2 \times 4$$

$$= \frac{100}{4} = 25 \text{ Watt}$$

At $t \rightarrow \infty$,

$C \rightarrow$ open circuit

Current through capacitor

$$I = I_0 [e^{-t/RC}]$$

$\therefore$ Power consumed is more than 25 Watt i.e. 36 Watt

Second Method

For capacitor

$$V = V_0 [1 - e^{-t/RC}]$$

$$= 5 [1 - e^{-t/8}]$$

$$i = \frac{d\theta}{dt} = \frac{CdV}{dt} = \frac{dV}{dt} = \frac{5}{8} e^{-t/8}$$

$$i = 2 \times \frac{5}{8} e^{-t/8}$$

Power in 4Ω resistor $P_R = I^2 R$

$$= \frac{25}{16} \times 4 e^{-t/4}$$

$$\text{Total power } P_T = \int_0^\infty P dt = \frac{25}{4} \int_0^\infty e^{-t/4} dt$$

$$= \frac{25}{4} \times \frac{1}{-1/4} e^{-t/4} \Big|_0^\infty = 25 \text{ joule}$$

35. The bridge is balanced wheat stone bridge $[Z_1/Z_2] = [Z_3/Z_4]$ then no current flow the detector elements. It means both in are at same potential

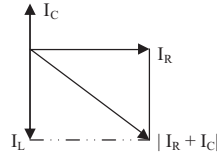
$$Z_{eq} = 4 \parallel 8 = \frac{4 \times 8}{12} = \frac{8}{3}$$

36. Current due to voltage source

$$i_v = \frac{4}{4+1} \times \frac{10}{4+4} = \frac{4}{5} \times \frac{50}{24} = \frac{10 \times 5}{5+6}$$

$$= \frac{10 \times 5}{5+6} = \frac{5}{3} \text{ A}$$

37.



$$I_C + I_L + I_R = 1$$

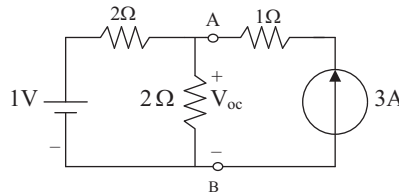
The parallel RLC circuit, $Q = |I_C|/I_R$

At resonance, $I_L = Q I_R$; $I_C = -Q I_R$

$$|I_R + I_L| > 1 \text{ mA}$$

38. It is required to find voltage across the terminals a and b.

With respect to node A Apply KCL



$$\frac{V_a - 1}{2} + \frac{V_a}{2} - 3 = 0$$

$$2V_a - 1 - 6 = 0$$

$$V_a = 3.5 \text{ V}$$

39. At, $t = (0^-)$ circuit is in steady state condition L is short circuit and it get change to maximum value.

$$i_L(0^-) = (50/20) = 2.5 \text{ Amp}$$

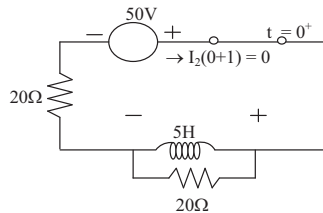
At $t = 0^+$ switch is open

$$i_L(0^+) = i_L(0^-)$$

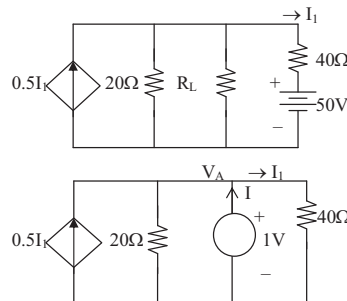
since, current in the inductor does not change instantaneous.

At $t = 0$, Switch is opened the inductor discharge through 20Ω resistor with current 2.5 A

$$\therefore V_x = 20 \times -2.5 = -50 \text{ V}$$



40.



Apply the KCL at node A

$$\frac{V_A}{20} + \frac{V_A}{40} - 0.5I_1 - I = 0$$

$$\text{or, } \frac{V_A}{20} + \frac{V_A}{40} - 0.5 \times \frac{V_A}{40} - I = 0$$

$$\text{or, } \frac{V_A}{20} + \frac{V_A}{40} = \frac{V_A}{80} = I$$

$$\text{or, } \frac{4V_A + 2V_A - V_A}{80} = 1$$

$$\text{or, } \frac{5V_A}{80} = I$$

$$\text{or, } \frac{V_A}{I} = \frac{80}{5} = 16 \Omega = Z_{eq}$$

For maximum power transfer load impedance should be equal to source impedance.

Second Method

Remove R_L final V_{th}

$$\frac{V_m}{20} + \left[\frac{V_m - 50}{50} \right] - 0.5 I_1 = 0 \quad (1)$$

$$I_1 = \frac{V_m - 50}{40} \quad (2)$$

From equation (1) and (2)

$$\frac{V_m}{20} + \frac{V_m - 50}{80} = 0$$

$$\frac{4V_m + V_m - 50}{80} = 0$$

$$V_m = \frac{50}{80} = 10 \text{ V}$$

Short circuit the R_L then

$$I_{sc} = +0.5 I_1 + \frac{50}{40} \quad (4)$$

$$I_1 = \frac{-50}{40} \quad (5)$$

From equation (4) and (5)

$$I_{sc} = -\frac{1}{2} \times \frac{50}{40} + \frac{50}{40} = \frac{1}{2} \times \frac{50}{4} = \frac{50}{80}$$

$$Z_{in} = \frac{V_{th}}{I_{sc}} = \frac{10}{50} \times 80 = 16 \Omega$$

41. $V_L = 400 \text{ V}$, $P = 1500 \text{ watt}$.

Power factor

$$\cos \theta = 0.844$$

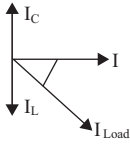
$$3 V_p I_p \cos \theta = 1500$$

$$\text{or, } 3 \cdot \frac{V_L}{\sqrt{3}} \cdot \left(\frac{V_L}{\sqrt{3} Z_L} \right) \cos \theta = 1500$$

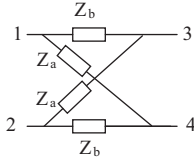
$$\text{or, } Z_L = \frac{V_L^2 \cdot \cos \theta}{1500} = \frac{400^2 \cdot (0.844)}{1500} = 90 \Omega$$

$$\text{and } \theta = \angle \cos^{-1}(0.844) = \angle 32.44^\circ$$

As power factor is leading, load is capacitive so angle is negative $\theta = -32.44^\circ$



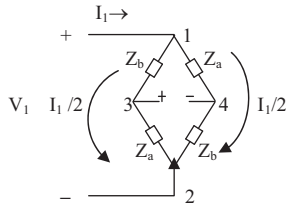
42.



$$V_1 = I_1 Z_{11} + I_2 Z_{12}$$

$$V_2 = I_1 Z_{21} + I_2 Z_{22}$$

$$Z_{11} = \left. \frac{V_1}{I_1} \right|_{I_2=0} = 0$$



KVL

$$V_1 = [I_1/2] \{Z_a + Z_b\}$$

$$0 = -V_2 - [I_1/2] Z_b + [I_1/2] Z_a$$

$$V_2 = [I_1/2] \{Z_a - Z_b\}$$

Where, $Z_1 = Z_b = 2$

$$Z_2 = Z_a = 2j$$

$$Z_{11} = [V_1/I_1] = [1/2] \{Z_a + Z_b\} = j + 1$$

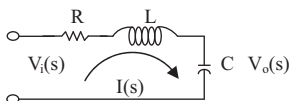
$$Z_{21} = [V_2/I_1] = [1/2] \{Z_a - Z_b\} = j - 1 = -1 + j$$

If series impedance in a circuit is equal then network is symmetrical. i.e., $Z_{11} = Z_{22}$

If cross arm impedance is equal then network is reciprocal i.e. $Z_{12} = Z_{21}$

$$\begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} = \begin{pmatrix} 1+j & -1+j \\ -1+j & 1+j \end{pmatrix}$$

43.



$$R = 10 \text{ k}\Omega, L = 10 \text{ mH}, C = 100 \text{ }\mu\text{F}$$

$$V_i(s) = R I(s) + L s I(s) + [1/Cs] I(s)$$

$$\text{And } V_o(s) = [1/Cs] I(s)$$

$$\text{Then, } \frac{V_o(s)}{V_i(s)} = \frac{1}{LCs^2 + RCs + 1}$$

$$\text{Or, } \frac{V_o(s)}{V_i(s)} = \frac{10^6}{s^2 + 10^6 s + 10^6}$$

44. $V(t) = u(t)$

Using KVL around the loop, we have

$$V(t) = Ri(t) + L \frac{di(t)}{dt} + \frac{1}{C} \int_0^\infty i(t) dt$$

Taking Laplace transformation both of sides, we have

$$V(s) = R I(s) + L s I(s) - L I(0+) + \frac{I(s)}{sC} + \frac{V_c(0+)}{s}$$

$$\frac{1}{s} = I(s) + s I(s) - 1 + \frac{I(s)}{s} - \frac{1}{s}$$

$$\frac{2}{s} + 1 = \frac{I(s)}{s}$$

$$I(s) = \frac{s+2}{s^2+s+1}$$

45. At, $t = 0^-$ i.e., final, condition it mean capacitor is open circuit and $L \rightarrow$ Short circuit

At, $t = 0^+$, i.e., initial condition it mean the voltage across capacitors is $-V$ i.e., $V_c(0^-) = V$

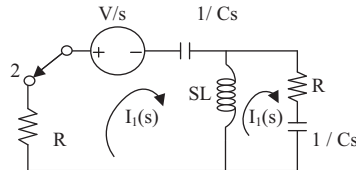
At $t = 0^+$ i.e., initial condition

$C \rightarrow$ Short and $L \rightarrow$ Open circuit

Capacitor in series with R is shorted, inductor open

Since loop is open circuit $e_i = 0$

46. Transformed circuit representation is as shown below



Using KVL in both the loops, we get

$$I_1(s) \cdot [1/Cs + sL + R] - I_2 \cdot sL + [V/s] = 0$$

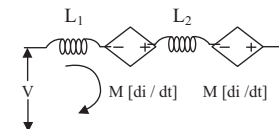
$$\text{And } I_2(s) [R + (1/Cs) + Ls] - I_1 Ls = 0$$

Writing in matrix form,

$$\begin{pmatrix} R + sL + \frac{1}{Cs} & -Ls \\ -Ls & R + Ls + \frac{1}{Cs} \end{pmatrix} \begin{pmatrix} I_1(s) \\ I_2(s) \end{pmatrix} = \begin{pmatrix} -V/s \\ 0 \end{pmatrix}$$

47. In a tree there is a no loop but (b) contain close loop.

48.



$$\begin{aligned} V &= L_1 \frac{di}{dt} - M \frac{di}{dt} + (L_2 - M) \frac{di}{dt} \\ &= (L_1 + L_2 - 2M) [di/dt] = L [di/dt] \\ L &= L_1 + L_2 - 2M \end{aligned}$$

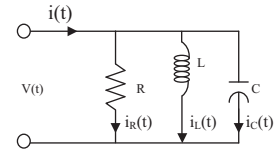
Second Method

$$L_{eq} = L_1 + L_2 \pm 2M$$

NOTE: + for positively complex and - for negative complex circuit

Hence compiling is negative as dots are on opposite ends.

49.



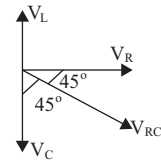
$$\omega = 2$$

$$i(t) = i_R(t) + i_L(t) + i_C(t)$$

$$i(t) = \frac{v(t)}{R} + \frac{v(t)}{j\omega L} + v(t) \times (j\omega C)$$

$$\begin{aligned} \Rightarrow i(t) &= \sin 2t [3 - 2j + 6j] \\ &= (3 + 4j) \sin 2t \\ &= \sqrt{3^2 + 4^2} \sin 2t \angle \tan^{-1} [4/3] \\ i(t) &= 5 \sin (2t + 53.1^\circ) \end{aligned}$$

50.



$$\begin{aligned} V_o(t) &= \frac{V_i(t)}{R + \frac{1}{j\omega C}} \times \frac{1}{j\omega C} = \frac{\sqrt{2} \sin 10^3 t}{j+1} \\ &= \sin (10^3 t - 45^\circ) \end{aligned}$$

51. $V_i(t) = R i(t) + L [di(t)/dt]$

With Laplace transformation, we have

$$V_i(s) = [R + Ls] I(s)$$

$$\text{Or, } I(s) = \frac{V_i(s)}{R + Ls} = \frac{1}{s(2+s)}$$

[Since, $V_i(s) = [1/s]$]

In time-domain, $i(t) = [u(t)/2] [1 - e^{-2t}]$

At $t = [1/2]$, $i(t) = 0.31$

And at $t = \infty$, $i(t) = 0.5$

52. $n_1 = n$; $n_2 = 1$

For and ideal transformer.

$$V_1 = n_1 V_2;$$

$$V_2 = n_2 V_1$$

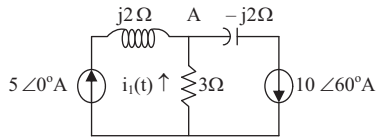
$$I_1 = -[1/n] I_2$$

$$I_2 = -n I_1$$

$$\begin{aligned}
 A &= [V_1/V_2] = n \\
 B &= -[V_1/I_2] = 0 \\
 C &= 0 \\
 D &= [-I_1/I_2] = [-1/n] = [1/n] \\
 D &= [1/n]
 \end{aligned}$$

$$\begin{aligned}
 53. \quad [V^2/4 R_L] &= [102/(4 \times 100)] \\
 &= [1/4] = 0.25 \text{ W}
 \end{aligned}$$

54.



By KCL at Node A

$$-5 \angle 0^\circ - I_1 + 10 \angle 60^\circ = 0$$

$$I_1 = 10 \angle 60^\circ - 5 \angle 0^\circ$$

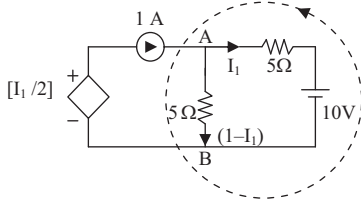
$$= 10 [\cos 60^\circ + j \sin 60^\circ] - 5$$

$$I_1 = 10 [1/2] + 10 [j \sqrt{3}/2] - 5$$

$$I_1 = \frac{10\sqrt{3}}{2} \angle 90^\circ \text{ amp}$$

$$\begin{aligned}
 55. \quad Z &= j5 \Omega + j2\Omega + j2\Omega + 2(j10) - 2(j10) \\
 &= j9\Omega
 \end{aligned}$$

56.



By KVL, in loop

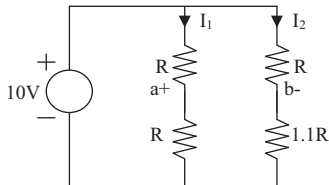
$$10 = -5I_1 + 5(1 - I_1) = 5 - 10I_1$$

$$I_1 = -[1/2]$$

$$V_{ab} = 5(1 - I_1) = 5[1 + (1/2)]$$

$$V_{ab} = 7.5$$

57.



$$I_1 = [10/2R] = [5/R]$$

$$I_2 = [10/2.1R]$$

$$= 4.76/R$$

$$V_{ab} = -R I_1 + I_2 R$$

$$= R [I_2 - I_1]$$

$$= [R/R] (4.76 - 5)$$

$$V_{ab} = -0.238$$

58. h-parameter standard equation

$$V_1 = h_{11} I_1 + h_{12} V_2 \quad (1)$$

$$I_2 = h_{21} I_1 + h_{22} V_2 \quad (2)$$

$$V_1 - 10I_1 - 20(I_1 + I_2) = 0;$$

$$V_2 - 20(I_1 + I_2) = 0$$

$$\Rightarrow V_1 - 30I_1 - 20I_2 = 0;$$

$$V_2 - 20I_1 - 20I_2 = 0$$

$$V_1 = 30I_1 + 20I_2 \quad (3)$$

$$V_2 = 20I_1 + 20I_2 \quad (4)$$

$$\Rightarrow 20I_2 = V_1 - 30I_1;$$

$$\Rightarrow 20I_1 = V_2 - 20I_1$$

$$V_1 - V_2 = 10I_1$$

$$\Rightarrow V_1 = V_2 + 10I_2$$

$$V_1 = 10I_1 + V_2 \quad (5)$$

$$\text{Now, } V_1 = h_{11} I_1 + h_{12} V_2 \quad (1)$$

Comparing equation (1) and (5) we get

$$h_{11} = 10 \text{ \& } h_{12} = 1$$

From equation (3) and (5)

$$20I_2 = V_1 - 30I_1 = V_2 + 10I_1 - 30I_1$$

$$= V_2 - 20I_1$$

$$I_2 = [1/20] V_2 - I_1 \quad (6)$$

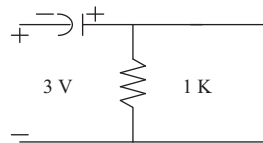
$$I_2 = h_{21} I_1 + h_{22} V_2 \quad (2)$$

Comparing equation (6) and (2) we get

$$h_{21} = -1 \text{ and } h_{22} = 0.05$$

$$\text{Hence, } h \text{ parameter are } \begin{pmatrix} 10 & 1 \\ -1 & 0.05 \end{pmatrix}$$

59.



$$\text{Time constant} = RC = 100 \text{ } \mu\text{sec.}$$

$$T = 2 \text{ sec} \gg 100 \text{ } \mu\text{sec.}$$

So, C is fully charged (opposite polarity)

$$V_{out} = -3$$

60. System $[1/(s+1)]$ gives change in output as

$$\frac{1}{\sqrt{1+1}} \angle -\tan^{-1} \frac{1}{1}$$

$$\frac{1}{\sqrt{2}} \angle -45^\circ$$

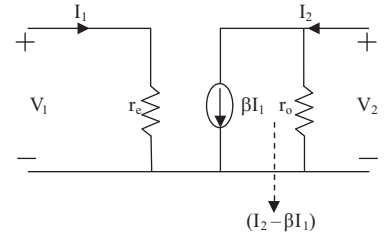
$$\text{Therefore output} = [1/\sqrt{2}] \sin [t - (\pi/4)]$$

61. $V_1 = I_1 r_e$

$$V_2 = -r_o (I_2 - \beta I_1)$$

$$V_2 = -\beta I_1 r_o + I_2 r_o$$

Compare with below equation

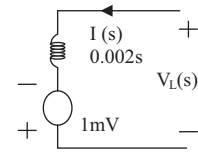


$$V_1 = Z_{11} I_1 + Z_{12} I_2$$

$$V_2 = Z_{21} I_1 + Z_{22} I_2$$

We get $Z_{12} = 0$ and $Z_{21} = -\beta r_o$ 62. Initial current $= i(0^-)$

$$V_L(s) = sLI(s) + L i(0^-)$$

Voltage source is represent by $L i(0^-) = 1\text{mV}$ 

$$L \times i(0^-) = 1 \text{ mV}$$

$$\Rightarrow 2 \times 10^{-3} \times i(0^-) = 1 \times 10^{-3}$$

$$\Rightarrow i(0^-) = [1/2] = 0.5 \text{ A}$$

63. At $t = 0$ i.e., under initial conditionC $\rightarrow$ Short circuit

$$\text{Hence output } V_o(0^+) = 0$$

At $t = \infty$, i.e., under steady stateC $\rightarrow$ Open circuit

$$\text{Hence output } V_o(\infty) = \frac{4}{5} \times V_i$$

$$= \frac{4}{5} \times 10 = 8$$

The equivalent resistance and capacitance can be calculated after short circuit all the source.

$$R_{eq} = 1 \parallel 4 = 0.8 \text{ k}\Omega$$

$$C_{eq} = 4 \parallel 1 = 5 \text{ } \mu\text{F}$$

$$\tau = R_{eq} C_{eq} = 0.8 \text{ k}\Omega \times 5 \text{ } \mu\text{F}$$

$$= 4 \text{ msec}$$

$$V_o(t) = V_o(\infty) - [V_o(\infty) - V_o(0)] e^{-t/\tau}$$

$$= 8 - [8 - 0] e^{-t/0.004}$$

$$= 8[1 - e^{-t/0.004}] \text{ volt}$$

64. For positive real function

$$\text{Re}[Z_2(s)] \geq 0$$

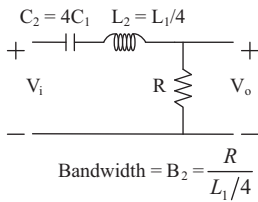
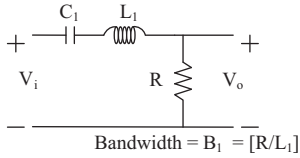
$$Z_2(s) = R_{neg} + \text{Re}(Z_1(j\omega)) + j \text{Im}(Z_1(j\omega))$$

$$\therefore R_{neg} + \operatorname{Re}[Z_1(j\omega)] \geq 0$$

$$\text{or } \operatorname{Re}[Z_1(j\omega)] \geq -R_{neg}$$

$$\text{or } \operatorname{Re}[Z_1(j\omega)] \geq |R_{neg}|$$

65.



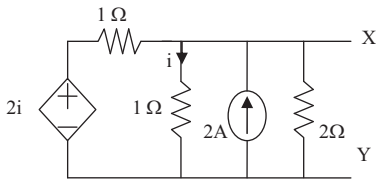
$$\frac{B_1}{B_2} = ?$$

For series RLC, Bandwidth = R/L

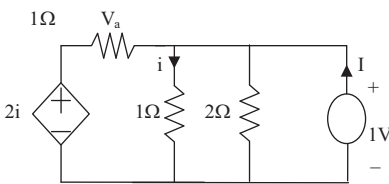
$$\therefore B_1 = \frac{R}{L_1}; B_2 = \frac{R}{L_1/4}$$

$$\therefore \frac{B_1}{B_2} = \frac{1}{4}$$

66.



For Thevenin's impedance R_{th} remove the independent source and dependence source remain as it is. Apply 1 volt source to the X, Y terminal and finding $R_{th} = [1/I]$



KCL at Node

$$\frac{2i - V_a}{1} = i + \frac{V_a}{2} - I$$

$$V_a = 1V, \quad i = \frac{IV}{1\Omega} = 1A, \text{ then}$$

$$\therefore 1 = 1 + \frac{1}{2} - I; \quad I = \frac{1}{2}$$

$$\therefore R_{th} = \frac{1}{I} = 2\Omega$$

For Thevenin's voltage V_{th}

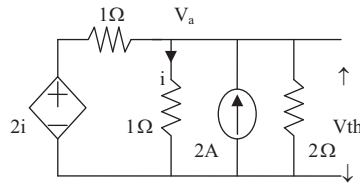
$$\frac{2i - V_a}{1} + 2 = i + \frac{V_a}{2}$$

$$\text{or, } 2i - i + 2 = V_a + \frac{V_a}{2} \quad \text{or, } i + 2 = 3\frac{V_a}{2}$$

$$\text{Also } V_a = i \times 1 = i$$

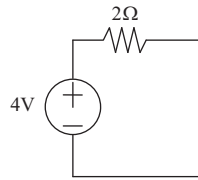
$$\therefore i + 2 = 3\frac{i}{2} \Rightarrow 2 = \frac{i}{2} \Rightarrow i = 4$$

$$\text{or } 2 = \frac{i}{2}$$

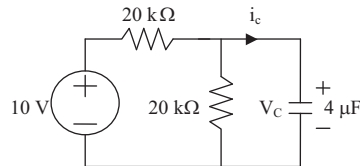


$$\text{or } i = 4$$

$$\therefore V_{th} = V_a = i = 4V$$



67.



$$\frac{10}{S} = 20,000 I(S) + \frac{20,000 I(S)}{20,000 \times 4 \times 10^{-6} S + 1}$$

$$\frac{10}{S} = 20,000 I(S) \left[1 + \frac{100/8}{S + \frac{100}{8}} \right]$$

$$I(S) = \frac{10}{S} \times 20,000 \times \left[\frac{S + \frac{100}{8}}{S + \frac{200}{8}} \right]$$

$$I_c(S) = \frac{20,000 I(S)}{20,000 + \frac{1}{4 \times 10^{-6} S}}$$

$$= \left[\frac{8S}{\frac{100}{8S} + 1} \right] \times \frac{10}{S} \times \frac{1}{20,000} \left[\frac{S + \frac{100}{8}}{S + \frac{200}{8}} \right]$$

$$= \left[\frac{(S)}{S + \frac{100}{8}} \right] \times \frac{10}{(S)} \times \frac{1}{20,000} \left[\frac{S + \frac{100}{8}}{S + 25} \right]$$

$$\therefore i_c = 0.0005 e^{-25t}$$

$$i_c = 0.5 e^{-25t} \text{ mA}$$

Second Method

$$i_c(t) = i_{c(\text{initial})} e^{-\frac{t}{RC}} + i_{c(\text{initial})} \left(1 - e^{-\frac{t}{RC}} \right)$$

$$i_c(t) = i_{c(\text{final})} + (i_{c(\text{initial})} - i_{c(\text{final})}) e^{-\frac{t}{RC}}$$

$$R' = 20 \parallel 20 = 10 \text{ k ohm's}$$

$$i_{c(\text{initial})} = 0; \quad i_{c(\text{final})} = \frac{10}{20} = 0.5$$

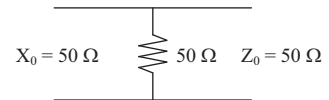
$$\text{Thus } i_c(t) = 0.5 e^{-25t}$$

$$\begin{aligned} 68. \quad R_{AB} &= \frac{(5-3j)(5+3j)}{(5-3j) + (5+3j)} \\ &= \frac{25+9}{10} = 3.4\Omega \end{aligned}$$

$$V_{AB} = R_{AB} \times I$$

$$= 3.4 \times 5 \angle 30 = 17 \angle 30$$

69.



Since no power is reflected on either port when any source is applied

$$\therefore S_{11} = S_{22} = 0$$

Since perfectly matched

$$\therefore S_{12} = S_{21} = 1$$

Hence S-matrix is

$$\begin{bmatrix} S_{12} & S_{11} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

70. For linear network

$$\text{Power} = |V| \times |I| = 4 \times 20 = 80$$

71. Mains current $A_3 = 13$ is vector sum of

$$A_1 \text{ \& } A_2; \quad A_3^2 = A_1^2 + A_2^2$$

$$A_2^2 = A_3^2 - A_1^2 = 13^2 - 5^2 = 12A$$

72. In steady state, entire voltage drop across the capacitor in inverse proportion of their capacitance as

$$V_2(t) = \frac{C_1}{C_1 + C_2} \cdot V$$

$$\text{Where } C_1 = 8 \mu F$$

$$C_2 = 2 \mu F$$

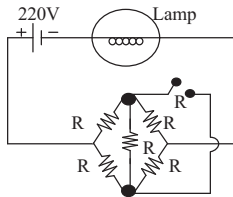
$$V_2(t) = [8/10] \times 10 = 8V$$

$$V_g(t) = \frac{C_2}{C_1 + C_2} \cdot V = \frac{2}{10} \cdot 10 = 2V$$

73. For two port reciprocal network;

$$h_{12} = -h_{21}$$

74.

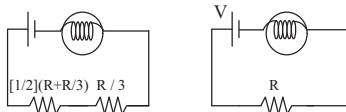
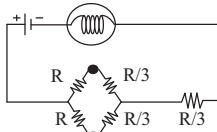


Voltage across the diagonal resistance = $20 \times [R/2R] = 10 \text{ V}$ from both directions, thus the net voltage is 0. This is equivalent to a short. When the switch is closed, then also diagonal resistance is shorted out. Hence the lamp intensity remains same. A mathematical analysis is given below:

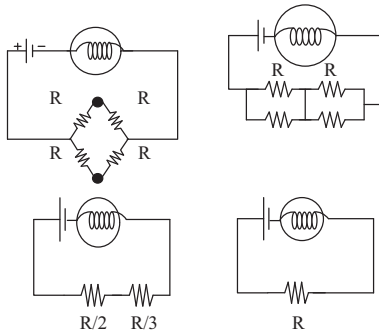
When the switch is open

The circuit is redrawn as follows by converting delta to star.

$$R_{eq} = \frac{R \times R}{3R} = \frac{R}{3}$$



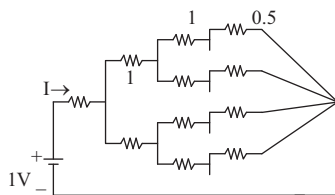
When the switch is closed



Thus the current through the lamp is same when the switch is both open and closed and also the intensity of lamp will be also same.

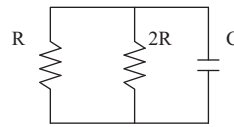
Hence choice (c) is correct.

75.



$$I = \frac{1}{1.875} = \frac{1000}{1875} = \frac{8}{15} \text{ A}$$

76. Resistance faced by C with the source shorted, is simplified as follows:

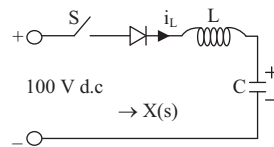


$$R_{eq} = \frac{R \times 2R}{3R} = \frac{2R}{3}$$

Time constant of the circuit,

$$\tau = R_{eq} \times C = \frac{2R}{3} \times C = \frac{2}{3} RC$$

77.



$$Z(s) = Ls + [1/Cs]$$

$$I_L(s) = \frac{100/s}{Ls + [1/Cs]} = \frac{100C}{LCs^2 + 1} = \frac{100}{L(s^2 + [1/LC])}$$

$$V_c(s) = \frac{I_L(s)}{Cs}, \text{ Since initial voltage}$$

$$V_c(0^-) = 0$$

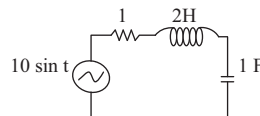
$$= \frac{100}{LCs(s^2 + [1/LC])}$$

The steady state voltage across the capacitor is

$$\lim_{t \rightarrow \infty} V_c(t) = \lim_{s \rightarrow 0} s V_c(s)$$

$$= \lim_{s \rightarrow 0} \frac{100 \text{ Volts}}{LC(s^2 + [1/LC])} = 100 \text{ V}$$

78. For d.c. voltage 5V would encounter an open circuit in the capacitor and hence the current is zero.



$$\text{For a.c. } i(t) = \frac{10 \sin t}{1 + j2 + [1/j]} \quad [\because \omega = 1]$$

$$= \frac{[10 \sin t] \times j}{j - 2 + 1}$$

$$= \frac{j10 \sin t}{1 + j} = \frac{10}{2} \sin(t) \angle (90^\circ - 45^\circ)$$

$$= \frac{10}{2} \sin(t - 45^\circ)$$

$$= 7.07 \sin(t - 45^\circ)$$

79. The input impedance of the circuit,

$$\begin{aligned} Z &= 10 + \left(\frac{1}{j\omega} \parallel 4j\omega + \frac{1}{j\omega} \right) \\ &= 10 + \left(\frac{1}{j\omega} \left\{ 4j\omega + \frac{1}{j\omega} \right\} \right) \\ &= 10 + \left(\frac{4 - (1/\omega^2)}{2j\omega + 4j\omega} \right) \\ &= 10 + \left(\frac{4 - (1/\omega^2)}{j[4\omega + 2/\omega]} \right) \end{aligned}$$

The circuit would resonate when imaginary part of impedance is zero. Therefore, $[1/\omega^2] = 4$

$$\text{Or } \omega = 0.5$$

80. Response for any input $u(t)$ is,

$$y(t) = \int_0^t h(t-\tau) u(\tau) d\tau$$

where impulse response, $h(t) = [d/dt] [s(t)]$ and $s(t)$ is the step response

$$\text{Hence } y(t) = \frac{d}{dt} \int_0^t s(t-\tau) y(\tau) d\tau$$

81. In a d.c. resistive network, a tree is defined as a set of branches that connects all nodes of the network but contains no loop. A proper tree is defined as one that contains all voltage sources and resistive network. All current sources and inductors are left for the co-tree. Answer (b) is not at all a tree. Answer (c) and (d) are trees but not a proper tree since it contains current sources. So the correct answer is (a).

82. The input admittance

$$\begin{aligned} Y_{in}(\omega) &= j\omega C + \frac{1}{R + j\omega L} \times \frac{R - j\omega L}{R - j\omega L} \\ &= \frac{R}{R^2 + (\omega L)^2} \times \left(j\omega C - \frac{j\omega L}{R^2 + (\omega L)^2} \right) \end{aligned}$$

For resonance $I_{in} [Y_{in}(\omega)]$ is zero

$$\therefore Y_{in}(\omega) = \frac{R}{R^2 + (\omega L)^2}$$

$$\therefore Z_{in}(\omega) = \frac{R^2 + (\omega L)^2}{R} = R + \frac{(\omega L)^2}{R} > R$$

Hence the circuit behaves like a pure resistor of value higher than R .

$$83. s(t) = \frac{At}{(T/2)} = \frac{2At}{T}; \quad 0 < t < T/2$$

$$= -A; \quad [T/2] < t < T$$

$$e_{rms} = \sqrt{\frac{1}{T} \int_0^T e^2(t) dt}$$

$$\begin{aligned}
 &= \sqrt{\frac{1}{T} \int_0^{T/2} \left(\frac{2At}{T} \right)^2 dt + \int_{T/2}^T A^2 dt} \\
 &= \sqrt{\frac{1}{T} \left(\frac{4A^2}{T^2} \frac{1}{3} \frac{T^3}{8} + A^2 \frac{T}{2} \right)} \\
 &= \sqrt{\frac{A^2}{6} + \frac{A^2}{2}} = \sqrt{\frac{2A^2}{3}} = \sqrt{\frac{2}{3}} A = A \sqrt{\frac{2}{3}}
 \end{aligned}$$

84. The periodic time (T) = 4ms = 4×10^{-3} sec

$$\therefore \text{Fundamental frequency } (f) = (1/T) = [10^3/4] = 250 \text{ Hz}$$

$$\therefore \text{Frequency of the 5th harmonic} = 520 \times 5 = 1250 \text{ Hz}$$

85. Voltage across the capacitor at any time t

$$V_c = V(1 - e^{-t/RC}) = 1 - e^{-t/RC}$$

$$\text{since } V = 1 \text{ Volt}$$

$$\therefore \frac{dv_c}{dt} = \frac{1}{RC} e^{-t/RC}$$

$$\text{At, } t = 0^+, \frac{dV_c}{dt} = \frac{1}{RC}$$

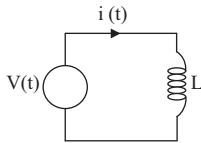
86. $\left(\frac{x}{a} + \frac{y}{b} = 1 \right)$

$$\Rightarrow \frac{1}{4 \times 10^{-3}} + V = 1; V = I \cdot R$$

$$R = [V/I] = [8/(4 \times 10^{-3})] = 2 \text{ K}$$

$$\begin{aligned} \text{Time constant of inductor} &= \frac{L}{R} = \frac{6 \times 10^{-3}}{2 \times 10^3} \\ &= 3 \mu \text{ sec} \end{aligned}$$

87. In the circuit given



$$\text{Constant dc} = u(t)$$

$$i_L(t) = [1/L] \int v_L dt$$

$$u(t) = [1/L] \int \delta(t) dt$$

Hence nature of voltage $v_L(t)$ must be an ideal impulse

88. Applying Thevenin's theorem

$$R_{eq} = 6 \Omega \parallel 4 \Omega = \frac{6 \times 4}{6 + 4} = \frac{24}{10} = 2.4 \Omega$$

$$\begin{aligned} V_{ab} &= 10 - 6 \times (5/10) = 10 - 6 \times 0.5 \\ &= 10 - 3 = 7 \text{ V.} \end{aligned}$$

Second method

Applying Millman theorem

$$V = \frac{V_1 \times Y_1 + V_2 \times Y_2}{Y_1 + Y_2}$$

$$V_{ab} = \frac{10 + [1/6] + 5 \times [1/4]}{[1/6] + [1/4]}$$

$$= \frac{[10/6] + [5/4]}{[1/6] + [1/4]}$$

$$= \frac{40 + 30}{10} = \frac{70}{10} = 7 \text{ V}$$

$$Y = Y_1 + Y_2; Z = Z_1 \parallel Z_2$$

$$R_{eq} = 6 \Omega \parallel 4 \Omega = \frac{6 \times 4}{6 + 4} = \frac{24}{10} = 2.4 \Omega$$

89. Effective inductance across AB terminals.

$$= L_1 + L_2 + L_3 - 2 M_{12} - 2 M_{13} + 2 M_{23}$$

$$= 4 + 5 + 6 - 2(1) - 2(3) + 2(2)$$

$$= 15 + 4 - 2 - 6$$

$$= 11 \text{ H}$$

90. The circuit is in resonance as voltage across L and C is double to the input

$$i = \frac{100}{20} = 5 \text{ A}$$

91. Use $Y - \Delta$ conversion between RBY and then use condition of a balanced Bridge

$$92. I_T = i_R + i_c$$

$$\text{Where } i_R = [V/R], i_c = C [dV/dt]$$

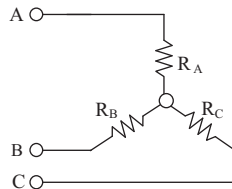
93. Applying KCL, $\frac{V}{4} + \frac{V - 2I}{2} = I$

$$\Rightarrow [V/I] = [8/3] \Omega$$

94. $Z'_L = 10 \angle 30^\circ [1/4]^2 = (0.54 + j0.31) \Omega$

$$\text{Total impedance} = (4.54 - j 1.69) \Omega$$

- 95.



$$\text{Given, } R_A + R_B = 6 \text{ With } C \text{ open}$$

$$R_B + R_C = 11$$

$$R_C + R_A = 9$$

$$\text{Then, } R_A + R_B + R_C = [26/2] = 13$$

$$R_A = 2 \Omega$$

96. $f(t)$ is even and has half wave symmetry.

$$\begin{aligned} 97. V_{rms} &= \sqrt{\frac{1}{T} \int_0^T x^2(t) dt} \\ &= \sqrt{\frac{1}{2(\pi/3)} \int_0^{2(\pi/3)} 100^2 dt} \\ &= \sqrt{\frac{3}{2\pi} \times 100^2 (t)_0^{2\pi/3}} \\ &= \sqrt{\frac{3}{2\pi} \times 100^2 \frac{2\pi}{3}} \\ V_{rms} &= 100 \text{ V} \end{aligned}$$

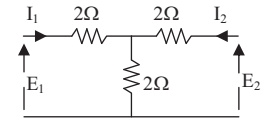
Second Method

$$\begin{aligned} V_{rms} &= \sqrt{\frac{A^2}{2\pi} \left[\int_0^{\pi/3} d\theta + \int_{\pi/3}^{2\pi/3} d\theta + \int_{2\pi/3}^{4\pi/3} d\theta + \int_{4\pi/3}^{5\pi/3} d\theta + \int_{5\pi/3}^{2\pi} d\theta \right]} \\ &= A \sqrt{\frac{1}{2\pi} \left[\frac{\pi}{3} - 0 + \frac{2\pi}{3} - \frac{\pi}{3} + \frac{4\pi}{3} - \frac{2\pi}{3} + \frac{5\pi}{3} - \frac{4\pi}{3} + 2\pi - \frac{5\pi}{3} \right]} \\ &= A = 100 \text{ Volt} \end{aligned}$$

98. $I_1 = Y_{11} E_1 + Y_{12} E_2$

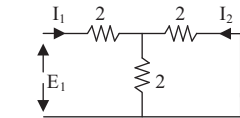
$$I_2 = Y_{21} E_1 + Y_{22} E_2$$

Short circuit E_2 , i.e., $E_2 = 0$

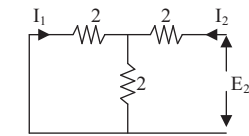


$$Y_{11} = \left. \frac{I_1}{E_1} \right|_{E_2=0} = [1/3];$$

$$Y_{21} = \left. \frac{I_2}{E_1} \right|_{E_2=0} = -[1/6]$$



Short circuit E_1 , i.e., $E_1 = 0$



$$Y_{12} = \left. \frac{I_1}{E_1} \right|_{E_2=0} = -[1/6];$$

$$Y_{22} = \left. \frac{I_2}{E_2} \right|_{E_1=0} = -[1/3]$$

Another Method

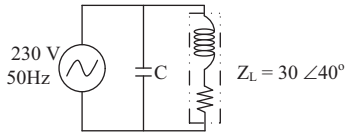
From the figure

$$Z = \begin{bmatrix} 4 & 2 \\ 2 & 4 \end{bmatrix}$$

$$|Z| = 16 - 4 = 12$$

$$\begin{aligned} Y = Z^{-1} &= \frac{1}{12} \begin{bmatrix} 4 & -2 \\ -2 & 4 \end{bmatrix} \\ &= \begin{bmatrix} 1/3 & -1/6 \\ -1/6 & 1/3 \end{bmatrix} \end{aligned}$$

99.



At unit power factor operation admittance of both branch

$$Y = j\omega C + [1/(30) \angle 40^\circ]$$

$$= j\omega C + \frac{1}{30(0.76 + j0.64)}$$

Equalizing imaginary part, we get, $C = 68.1 \mu\text{F}$

100. $R_{\text{eq}} = 11 \text{ k}\Omega$

$$C = 11 \text{ nF}$$

$$R_{\text{eq}} C = 11 \times 10^3 \times 11 \times 10^{-9} = 121 \mu\text{sec}$$

$$V_c(t) = V \left[1 - e^{-\frac{t}{RC}} \right]$$

$$V_c(t) \Big|_{\text{max}} = V \left[1 - e^{-\frac{10}{121}} \right]$$

$$= 11 \left[1 - e^{-\frac{10}{121}} \right] \cong 0.87$$

101. Here V and I are in phase, it mean circuit is under resonance then j terms must be zero.

$$-j12 + j8 + j8 + j2x = 0$$

Where x is mutual inductance

$$\text{or, } -j12 + j16 + j2x = 0$$

$$\text{or, } 2x = -4$$

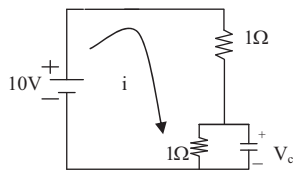
$$\text{or, } x = -2$$

$$K = \frac{M}{\sqrt{L_1 L_2}} = \frac{2}{\sqrt{8 \times 8}} = \frac{2}{8} = 0.25$$

103. In steady state $L \rightarrow$ short circuit and

$C \rightarrow$ Output circuit.

After steady state is reached, the equivalent circuit can be drawn as



$$i = \frac{10}{2} = 5 \text{ A}$$

$$\text{obviously, } V_c = 5 \times 1 = 5 \text{ V}$$

104. For 0–2 sec, current, i changes with i.e.,

$$\frac{di}{dt} = \frac{6}{2} (\text{amp})/s$$

$$V_L = L \frac{di}{dt} = 2 \times \frac{6}{2} = 6 \text{ V,}$$

$$W = v i t = 6 \times 6 \times 2 = 72 \text{ J}$$

For 2–4 sec; for steady current, $V = I \times$

$$R = 6 \times 1 = 6 \text{ V}$$

$$W = 6 \times 6 \times 2 = 72 \text{ J}$$

$$\text{Total energy absorbed} = 72 \text{ J} + 72 \text{ J} = 144 \text{ J}$$

105. Current through capacitor

$$i_c = C \frac{dv_c}{dt} = 1 \times \frac{d}{dt} (4 \sin 2t) = 8 \cos 2t$$

KCL at node

$$-2 + 1 - 8 \cos 2t + i_L = 0$$

$$i_L = 1 + 8 \cos 2t$$

$$v_L = L \frac{di_L}{dt} = 2 \frac{d}{dt} (1 + 8 \cos 2t)$$

$$= -32 \sin 2t$$

106. $Z_1 = 10 \angle -60^\circ = 10 \cos(-60) + j \sin(-60)$

$$Z_2 = 10 \angle 60^\circ = [10 \cos 60 + j \sin 60];$$

$$Z_3 = 50 \angle 53.13^\circ = 50 [\cos 53.13 + j \sin 53.13]$$

$$Z_1 \parallel Z_2 = \frac{(5 - j8.66)(5 + j8.66)}{5 - j8.66 + 5 + j8.66}$$

$$= \frac{25 + 75}{10} = 10$$

$$Z_{\text{Th}} = [Z_1 \parallel Z_2] + Z_3 = 10 + 30 + j40 = 40 + j40$$

$$= \sqrt{40^2 + 40^2} \angle 45^\circ = 56.6 \angle 45^\circ$$

107. Given that $V_L = V_C = 2V_R$,

Therefore $V_L = V_C$

Or $X_L = X_C$, represent a resonance condition and

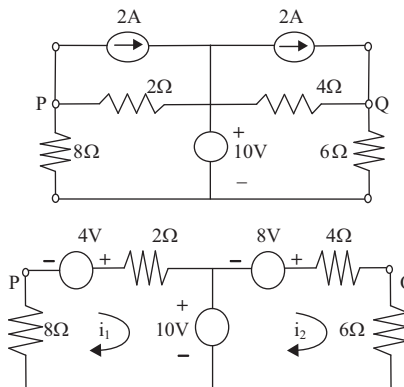
$$\therefore \text{current, } I = \frac{5}{R} = \frac{5}{5} = 1 \text{ A}$$

Now, V_L (Voltage across L) = $2V_R = 10$

$$\text{or } I \omega L = 10$$

$$\text{or } L = \frac{10}{\omega} = \frac{10}{2\pi f} = \frac{10}{2\pi \cdot 50} = 31.8 \text{ mH}$$

108. The current source is converted into voltage source Apply KVL in loop.



$$-4 + 10 + 10 i_1 = 0, i_1 = -\frac{6}{10} = -0.6 \text{ A}$$

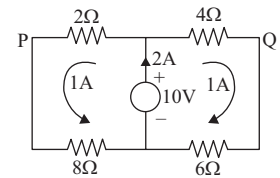
$$-10 - 8 + 10 i_2 = 0, 10 i_2 = \frac{18}{10} = 1.8 \text{ A}$$

$$V_{PQ} = -4 + (-0.6) - 8 + 4(1.8)$$

$$V_{PQ} = -4 - 1.2 - 8 + 7.2 = -6 \text{ V}$$

Second Method

Consider only voltage source, open circuit the current source

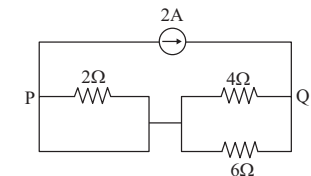


$$V_P = 8 \times 1 = 8 \text{ V}$$

$$V_Q = 6 \times 1 = 6 \text{ V}$$

$$V_{PQ1} = 8 - 6 = 2 \text{ V}$$

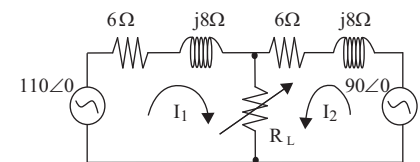
Consider only current source, Short circuit the voltage source



$$V_{PQ2} = -2[2.4 + 1.6] = -8 \text{ V}$$

$$V_{PQ} = -8 + 2 = -6 \text{ V}$$

109.



Thevenin resistance looking from R_L after shorting sources is

$$(6 + j8) \parallel (6 + j8) = 3 + j4$$

$$R_L = \sqrt{3^2 + 4^2} = 5 \Omega$$

$$\text{Now, } 110 = (6 + j8 + 5) I_1 + 5 I_2 \quad (1)$$

$$\text{and } 90 = (6 + j8 + 5) I_2 + 5 I_1 \quad (2)$$

Solving these two equations, we get

$$I_1 = 5.5 - 2.75j$$

$$I_2 = 4.5 - 2.2j$$

$$\Rightarrow \text{Total current in } R_L = I_1 + I_2$$

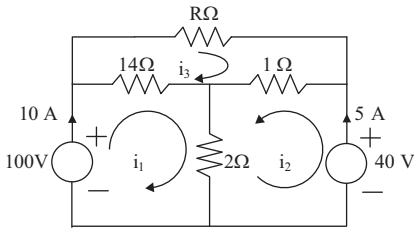
$$= (10 - 4.55j) \text{ A}$$

$$= 11.15 \text{ A}$$

Power absorbed by $R_L = I^2 R$

$$= (11.15)^2 \times 5 = 625 \text{ W}$$

110.



Apply the KVL in all three loop

$$100 = 16 i_1 + 2 i_2 - 14 i_3 \quad (1)$$

$$0 = -14 i_1 + i_2 + (15 + R) i_3 \quad (2)$$

$$i_1 = 10 \text{ A and } i_2 = 5 \text{ A}$$

From equation (1) and (2)

$$100 = 160 + 10 - 14 i_3$$

$$i_3 = \frac{70}{14} = 5$$

$$0 = -140 + 5 + (15 + R) 5$$

$$-(15 + R) 5 = -135, R = 27 - 15 = 12 \Omega$$

111. When switch is ON at $t = 0$ capacitor is short circuit and inductor is open circuit.

$$\therefore 4 \parallel 4 = 2 \Omega,$$

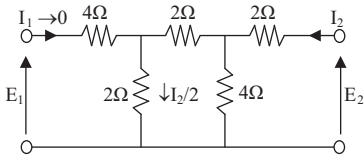
circuit total resistance, $3 + 2 = 5 \Omega$

$$\text{source current } I = \frac{10}{5} = 2 \text{ A}$$

$$\text{current through } 4 \Omega \text{ resistance} = \frac{2}{2} = 1 \text{ A}$$

Voltage across 4Ω resistance $= 4 \times 1 = 4 \text{ V}$ as inductor is parallel with resistance.

112.



$$h_{12} = \frac{E_1}{E_2} \bigg|_{I_1=0}, E_2 = 2I_2 + \frac{I_2}{2} \times 4 = 4I_2$$

$$E_1 = \frac{I_2}{2} \times 2 = I_2$$

$$\frac{E_1}{E_2} = \frac{I_2}{4I_2} = 0.25$$

113. Resistance does not play any role for resonance frequency. The given circuit is parallel LC circuit,

Admittance of given circuit,

$$Y = Y_L + Y_C = \frac{1}{j\omega L} + \frac{1}{Z}$$

At resonance, j term must be equal to zero i.e.,

$$\frac{1}{j\omega L} + \frac{1}{Z} = 0$$

$$\text{or } \frac{-1}{j\omega L} = \frac{1}{Z} \quad (1)$$

$$\text{or } \frac{j}{\omega L} = \frac{1}{Z}$$

$$\text{or } Z = \frac{\omega L}{j} \text{ i.e., Capacitive}$$

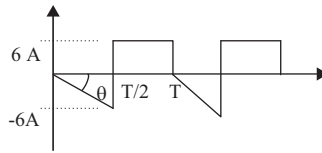
$$\text{or } \frac{1}{j\omega L} = \frac{\omega L}{j}$$

$$C = \frac{1}{\omega^2 L} = 0.05 \mu\text{F}.$$

114. Straight line equation, $y = mt + C$

When $m = \text{slop of line} = \tan \theta$.

$$\text{then, } m = \frac{-6}{T/2} = \frac{-12}{T} \text{ and } C = 0$$



$$f(t) = mt; \quad 0 \leq t \leq T/2$$

$$= 6; \quad T/2 \leq t \leq T$$

rms value for any waveform

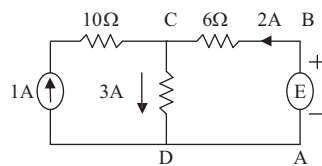
$$= \sqrt{\frac{1}{T} \int_0^T f^2(t) \cdot dt}$$

$$= \left[\frac{1}{T} \left(\int_0^{T/2} (mt)^2 \cdot dt + \int_{T/2}^T 6^2 \cdot dt \right) \right]^{1/2}$$

$$= \left[\frac{1}{T} \left(\frac{144}{T^2} \times \frac{T^3}{3 \times 8} + 36 \times \frac{T}{2} \right) \right]^{1/2}$$

$$= [6 + 18]^{1/2} = \sqrt{24} = 2\sqrt{6}$$

115.



Apply KVL in loop ABCD

$$-E + 6 \times 2 + 6 \times 3 = 0$$

$$E = 2 \times 6 + 3 \times 6$$

$$= 12 + 18 = 30 \text{ V}$$

116. Star-delta conversion is carried out by applying the formula w.r.t. diagram.

$$R_1 = \frac{R_a R_c}{R_a + R_b + R_c} = \frac{100}{40} = 2.5 \Omega$$

$$R_2 = \frac{R_a R_c}{R_a + R_b + R_c} = \frac{200}{40} = 5 \Omega$$

$$R_b = \frac{R_a R_b}{R_a + R_b + R_c} = \frac{200}{40} = 5 \Omega$$

117. From the diagram given in the question paper,

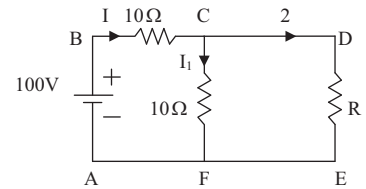
$$I_R = Y_R \cdot E = 0.5 \angle 0^\circ \cdot 10 \angle 0^\circ = 5 \angle 0^\circ \text{ A}$$

$$I_L = Y_L \cdot E = 1.5 \angle -90^\circ \cdot 10 \angle 0^\circ = 15 \angle -90^\circ \text{ A}$$

$$I_C = Y_C \cdot E = 0.3 \angle 90^\circ \cdot 10 \angle 0^\circ = 3 \angle 90^\circ \text{ A}$$

$$\bar{I} = \bar{I}_R + \bar{I}_L + \bar{I}_C = 5 - j15 + j3 = (5 - j12).$$

118. Applying KVL, in loop ABCF



$$-100 + 10 I + 10(I - 2) = 0$$

$$\Rightarrow 20 I = 100 + 20 = 120$$

$$\Rightarrow I = 6 \text{ A}.$$

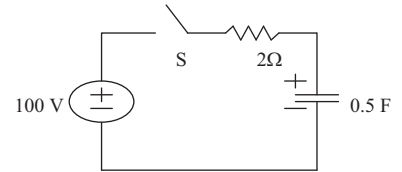
$$I_1 = I - 2 = 6 - 2 = 4 \text{ A}$$

Hence voltage drop across resistance R,

$$V_R = I_1 \cdot 10 = 4 \times 10 = 40 \text{ V} = 2R$$

$$\therefore R = \frac{40}{2} = 20 \Omega$$

119.



$$V = IR + \frac{1}{C} \int I dt$$

$$\text{Or } R \cdot \frac{dq}{dt} + \frac{1}{C} q = 100$$

$$\text{Or } (100 - q) = RC \frac{dq}{dt}$$

$$\int_{q_0}^q \frac{dq}{(100 - q)} = \frac{1}{RC} \int_0^t dt$$

$$\Rightarrow \ln [100 - q]_{q_0}^q = \frac{t}{RC}$$

$$\Rightarrow \ln \left[\frac{100 - q}{100 - q_0} \right]^{-1} = \frac{t}{RC}$$

$$\Rightarrow \ln \left[\frac{100 - q}{100 - q_0} \right] = \frac{-t}{RC}$$

$$\Rightarrow 100 - q = (100 - q_0) e^{-t/RC}$$

$$\Rightarrow \frac{dq}{dt} = (100 - q_0) e^{-t/RC} \left(\frac{1}{RC} \right)$$

$$i = \frac{(100 - q_0) e^{-t/RC}}{RC} = 40 e^{-1} = 14.7$$

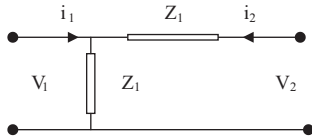
120. $10\ \Omega \parallel 10\ \Omega = 5\ \Omega$

KVL in loop, $-100 + (R + 5) 8 = 0$

or $-100 + 8R + 40 = 0$

or $R = \frac{60}{8} = 7.5$

121.



Z - Parameter represented as

$$V_1 = z_{11} I_1 + z_{12} I_2$$

$$V_2 = z_{21} I_1 + z_{22} I_2$$

$$z_{11} = \left. \frac{V_1}{I_1} \right|_{I_2=0} = \frac{Z_1 I_1}{I_1} = Z_1$$

$$z_{21} = \left. \frac{V_2}{I_1} \right|_{I_2=0} = \frac{Z_2 I_1}{I_1} = Z_2$$

$$z_{12} = \left. \frac{V_1}{I_2} \right|_{I_1=0} = \frac{Z_1 I_2}{I_2} = Z_1$$

$$z_{22} = \left. \frac{V_2}{I_2} \right|_{I_1=0} = \frac{(Z_1 + Z_2) I_2}{I_2} = Z_1 + Z_2$$

$$Z\text{-matrix} = \begin{bmatrix} Z_1 & Z_1 \\ Z_1 & Z_1 + Z_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix}$$

122. At $t = 0$, the capacitor voltage $V_c = 0$

At steady state, capacitor is open circuit i.e., at $t \rightarrow \infty$,

$$V_c = \frac{10}{10+10} \times 20 = 10V$$

$$= \left[\frac{1}{2\pi} \int_0^{2\pi} 300 dt \right]^{1/2} = \sqrt{300} = 17.3\ A$$

123. At $f = 100\ \text{Hz}$; $V_R = V_L$; $R = X_L = \omega L$

$$V_{rms} = \frac{V_{in}}{(\sqrt{2})}; V_{in} = (\sqrt{2}) V_{rms}$$

$$\text{At } f = 50\ \text{Hz}, X_L = \frac{\omega L}{2};$$

$$Z = \sqrt{R^2 + \frac{\omega^2 L^2}{4}}$$

$$I_{in} = \frac{V_{in}}{\sqrt{R^2 + \frac{\omega^2 L^2}{4}}} = \frac{V_{in}}{\sqrt{\omega^2 L^2 + \frac{\omega^2 L^2}{4}}} = \frac{2V_{in}}{\omega L \sqrt{5}}$$

$$V_{new} = \frac{2V_{in}}{\omega L \sqrt{5}} \times R = \frac{2V_{in}}{\omega L \sqrt{5}} \cdot \omega L = \frac{2V_{in}}{\sqrt{5}}$$

$$V_{new} = \frac{2\sqrt{2} V_{rms}}{\sqrt{5}} = \sqrt{\frac{8}{5}} V_{rms}$$

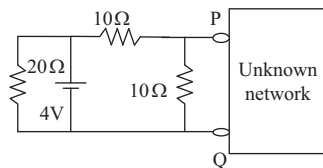
124. $V(t) = \frac{2t}{T}, 0 \leq t \leq \frac{T}{2}$

$$= 0; \frac{T}{2} \leq t \leq T$$

$$\begin{aligned} V(t)_{rms} &= \sqrt{\frac{1}{T} \int_0^T |V(t)|^2 dt} \\ &= \sqrt{\frac{1}{T} \int_0^{T/2} \frac{4}{T^2} t^2 dt} \\ &= \sqrt{\frac{1}{T} \cdot \frac{4}{T^2} \cdot \frac{t^3}{3} \Big|_0^{T/2}} = \sqrt{\frac{4}{T^3} \cdot \frac{T^3}{8 \times 3}} = \sqrt{\frac{1}{6}} \end{aligned}$$

125. At, $t = 0^-$ the circuit is in steady state inductor behave as short circuit, the current through the inductor $i(0^-) = 10/10 = 1\text{A}$. The current through the inductor does not change instantaneously. Therefore $i(0^-) = i(0^+) = 1\text{A}$.

126.



For Z_{eq} , short circuit the voltage source and open circuit the current source, in present case $20\ \Omega$ is also short circuit, therefore net impedance,

$$Z_{th} = 10 \parallel 10 = 5\ \Omega$$

For V_{oc} , in Parallel circuit
Current through $4V$ source

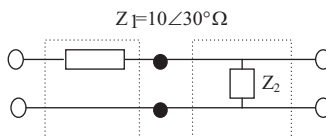
$$I = \frac{4}{20 \parallel (10+10)} = \frac{4}{10} = 0.4$$

$$I_{PQ} = 0.2\ \text{A}$$

$$V_{oc} = V_{PQ} = 0.2 \times 10 = 2V$$

$$127. \begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

$$B = \left. \frac{V_1}{I_2} \right|_{V_2=0}, C = \left. \frac{I_1}{V_2} \right|_{I_2=0}$$

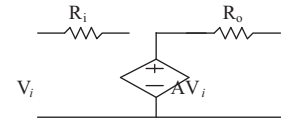


$$C = \frac{V_1 / (Z_1 + Z_2)}{\frac{V_1}{Z_1 + Z_2} \times Z_2} = \frac{1}{Z_2}$$

$$Z_2 = \frac{1}{C} = \frac{1}{0.025 \angle 45^\circ} = 40 \angle -45^\circ\ \Omega$$

128. Open circuit the current source for Z_{th}
 $Z_{th} = 1 - j + j2 = (1 + j)\ \Omega = \sqrt{2} \angle 45^\circ$
 $V_{th} = \sqrt{2} \angle 45^\circ \times 1 \angle 0^\circ = \sqrt{2} \angle 45^\circ\ \text{V}$

129.



$$R_{in} = \infty$$

$$R_{out} = 10\ \Omega$$

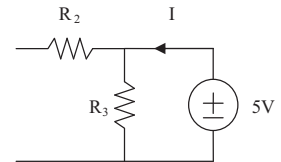
$$V_{out} = AV_{in} = 1\ \text{V}$$

130. By applying superposition theorem

1. Assume the current source = 0

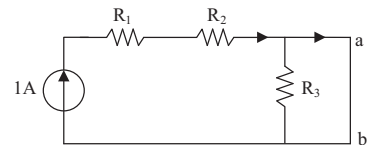
Since, voltage source is dc, all the inductors will behave like a short circuit while capacitors will behave like an open circuit, therefore after simplifying the circuit, we have

$$\text{Current, } I = [5 / 1] = 5\ \text{Amp}$$

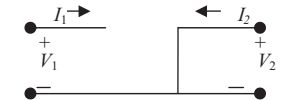


2. Assuming the voltage source to be zero R_3 is shorted

$\therefore$ No current will flow through it and $I_{ab} = 1\ \text{Amp}$.



131.



Parameter represent the component
H parameter are given by relations

$$V_1 = h_{11} I_1 + h_{12} V_2$$

$$I_1 = h_{11}' I_1' + h_{22}' V_2$$

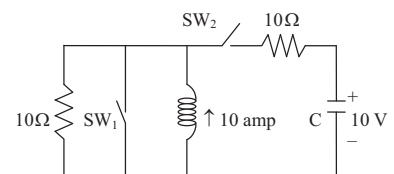
here all the parameter are '0' so

$$[h] = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$$

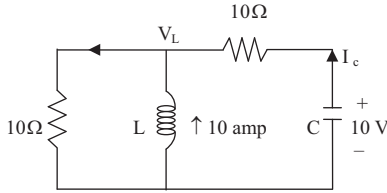
132. In resonance circuit, voltage V_1 and current I are in phase, The voltage across the capacitor lag the current by 90° .

Hence answer is (a)

133.



At $t = 0^-$, SW_2 is closed and SW_1 is opened



Voltage across $L = V_L$

Apply KCL at Node

$$\frac{V_L}{10} = 10 + \frac{10 - V_L}{10}$$

$$\frac{V_L}{5} = 11 \text{ V}; \quad V_L = 55 \text{ V}$$

Voltage across C and current through the L does not change instantaneously

KVL in load loop

Therefore, at $t = 0^+$

$$-10 + 10 \times I_c + V_L$$

$$V_c = 10 \times I_c + V_L$$

$$10 = 10 I_c + 55$$

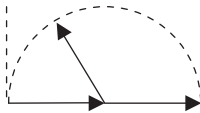
$$I_c = -4.5$$

Another Way

Current through C will be

$$\frac{V_L - 10}{10} = \frac{55 - 10}{10} = 4.5 \text{ A}$$

135.



$$V_{yx} = V_x - V_y \text{ V}$$

$$= V - 0 \text{ for } R = \infty = V - 2 \text{ V} \quad R = 0$$

CHAPTER 5

LEVEL 1

1. $v_p v_g = c^2$

2. Continuity equation

$$\oint \vec{J} \cdot d\vec{s} = \frac{-d}{dt} \iiint \rho \, dv$$

$$\nabla \cdot \vec{J} = -\frac{\partial \rho}{\partial t}$$

For steady current $\nabla \cdot \vec{J} = 0$

3. $Z = \sqrt{\frac{R + j\omega L}{G + j\omega C}}, \quad \gamma = \alpha + j\beta$

∴ For lossless, $R = 0, G = 0, \alpha = 0, \beta = |\gamma|$

4. $\left| \frac{E}{H} \right| = \eta = \sqrt{\mu/\epsilon}$

5. $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} = -\mu \frac{\partial \vec{H}}{\partial t}$

6. $\nabla \cdot \vec{D} = \rho$
 $\nabla \cdot \epsilon_0 \vec{E} = \rho$
 $\nabla \cdot \vec{E} = \rho/\epsilon_0$

7. For lossy transmission line, input impedance is given by

$$Z_{in} = Z_o \left(\frac{Z_L + Z_o \tanh \gamma l}{Z_o + Z_L \tanh \gamma l} \right)$$

For lossless transmission line

$$Z_{in} = Z_o \left(\frac{Z_L + j Z_o \tan \beta l}{Z_o + j Z_L \tan \beta l} \right)$$

Input impedance of a loss-less transmission line for various lengths is given by

$$\beta = [2\pi/\lambda]; \quad \ell = \lambda/8$$

$$\beta \ell = \frac{2\pi}{\lambda} \times \frac{\lambda}{8} = \frac{\pi}{4}$$

$$Z_{in} = Z_o \left(\frac{Z_L + Z_o}{Z_o + Z_L} \right)$$

When the line is short circuited ($Z_L = 0$)

$$Z_{in} = Z_{sc} = j Z_o \tan \beta \ell$$

$$\beta \ell = \frac{\pi}{4}; \quad \tan \pi/4 = 1$$

$$Z_{in} = j Z_o$$

Which Indicate inductive impedance

8. The boundary conditions for magnetic field are given by

$$B_{n1} - B_{n2} = 0 \quad \text{or,} \quad \mu_1 H_{n1} = \mu_2 H_{n2} \quad (1)$$

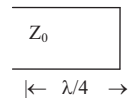
$$\text{and, } H_{t1} - H_{t2} = J_s$$

if $J_s = 0$, then

$$H_{t1} = H_{t2} \quad (2)$$

Now form equation (1) and (2) $H_1 = H_2$

9. $Z_{in} = Z_o \cdot \frac{Z_L + Z_o \tan \gamma l}{Z_o + Z_L \tan \gamma l}$
 $= Z_o \frac{(Z_L + Z_o \tan(\pi/2))}{(Z_o + Z_L \tan(\pi/2))} = \frac{Z_o^L}{Z_L}$



Where R is the series resistance per unit length of the line

For losses line, $R = 0$ and then Z_{in} is infinite

10. The Laplacian of a scalar field V is the divergence of the gradient of V .
 Laplacian $\nabla^2 V = \nabla \cdot \nabla V = \nabla^2 V$
 $(\omega t + \pi/2)$

13. The absorption has broad maximum in the vicinity of gyro-frequency (1.2–1.4 MHz) in the reflected wave in the earth's magnetic field in Smith chart, the distance towards the load is always measured in clock wise direction.

The gyro or cyclotron frequency is number of revolution per second of a particle in circular path

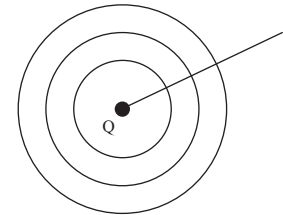
$$f = \frac{V}{2\pi R} - \frac{eB}{2\pi m} r/s$$

14. The short circuited stubs are preferred because open-circuited pieces of transmission line to radiate from the open end.

15. Corresponding to the magnetic vector potential $\vec{A}$ that yields the magnetic field strength due to electrical current through $\mu \vec{H} = \nabla \times \vec{A}$, there is similarly an electric vector potential $\vec{F}$ that yield the electric field due to magnetic current $\epsilon \vec{E} = -\nabla \times \vec{F}$ also $\vec{H} = -\nabla F - j\omega \vec{F}$

18. Quarter wave transformer behaves as tank circuit or series resonant circuit which, represent resistive network.

19.



$$V = \frac{Q}{4\pi\epsilon r}$$

Where Q = Point charge

r = radius of spheres

21. Coaxial support all frequency. There is no cut off frequency for propagation but attenuate the high frequency.

23. For a transmission line characteristic impedance is given by

$$Z_o = \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}}$$

For loss less line $R = G = 0$ then

$$Z_o = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{\frac{L}{C}}$$

24. For $\ell = \frac{\lambda}{4}$; $Z_{in} = \frac{Z_o^2}{Z_L}$

For short circuit termination, $Z_L = 0$

$$Z_{in} = \frac{Z_o^2}{Z_L} = \infty = \text{infinity}$$

25. At high frequency impedance parameter varies because internal inductance and capacitance comes to account

28. This shows a time varying electric field traveling with speed c along z axis in a plane perpendicular to the plane containing time varying magnetic field (B_x), so that the magnitudes of both are same. This is the property of an electro-magnetic wave as established by Maxwell's equations.

29. Consider shows a parallel plate capacitor and during charging, a current I is passing through the connectors. S is Poynting vector which is pointing every where radially into the volume and is defined as rate of energy flow per unit area in a plane electromagnetic wave [$S = (1/\mu) E \times B$] and direction of S gives the direction in which energy moves.

The rate at which energy flows into the volume between the plates

$$\int \vec{S} \cdot d\vec{A} = Ad \cdot [d/dt] \left[\frac{1}{2} \epsilon_0 E^2 \right]$$

where E is instantaneous value of electric field

Thus, energy stored in the capacitor does not enter through the connecting wires but through the space surrounding the wire and plates of capacitor.

30. Reflector, coefficient is given by, K_r

$$\left| \frac{Z_L - Z_0}{Z_L + Z_0} \right|$$

When, $Z_L = Z_0$, $K_r = 0$

31. $VSWR = \frac{K_r + 1}{K_r - 1}$

Where, K_r is the reflection coefficient

Since, $VSWR = 2$ therefore, $2 = \frac{K_r + 1}{K_r - 1}$

$$\text{Or } K_r = \frac{1}{3}$$

33. When a transmission line of high characteristic impedance is to be connected to a low impedance load, or vice-versa, the $[\lambda/4]$ transformer of as suitable Z_0 can as a connecting link for impedance matching. The $[\lambda/4]$ transformer is inherently a narrow band device, for it can be exactly a quarter wavelength at one frequency only.

43. A balun or balance to unbalance transformer is a circuit element used to connect a balanced line (Parallel wire line) to an unbalanced line (Coaxial) or antenna. Commonly it is used to connect unbalanced (coaxial) line to a balanced antenna such as dipole.

45. $\int_s \vec{J} \cdot d\vec{s}$ implies that the net current of closed surface is zero, which is the Kirchhoff's current law for direct current at nodes.

46. $\vec{B} = B_0 \cos \omega t \hat{i}_y$

$$\begin{aligned} \text{Total flux} &= \text{Area} \times \text{flux density} \\ &= ab \times B_0 \cos \omega t \end{aligned}$$

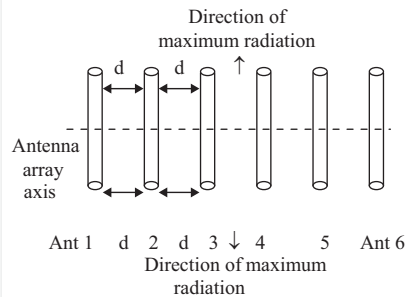
emf induce is given by change of flux.

$$\begin{aligned} |e(t)| &= \frac{d}{dt} (ab B_0 \cos \omega t) \\ &= ab B_0 \omega \sin \omega t \end{aligned}$$

47. Broad side Array

Broad-side array is one in which a number of identical parallel antenna are set up along a line drawn perpendicular to their respective axis.

In the broad-side array, individual antennas (at elements) are equally spaced along a line and each element is fed with a current of equal magnitude, all in the same phase. By doing so, this arrangement fires in Broad side direction (i.e., perpendicular to the line of array axis) where there are maximum radiation and relatively little radiation in other direction hence radiation pattern of Broadside array is Bidirectional.



(a) Broadside Array arrangement

48. Wavelength $\lambda = \frac{2\pi}{\beta}$

Where, Phase constant $\beta = \sqrt{\frac{\omega\mu\sigma}{2}}$ (for good conductors)

$$\lambda = \frac{2\pi\sqrt{2}}{\sqrt{\omega\mu\sigma}}$$

Thus on doubling the frequency (ω),

λ will become $\frac{1}{\sqrt{2}}$ times the original value.

49. Since the lines are identical and also the load resistance are equal, the time constants of both are equal. For both of lines, the time for the voltage of fall down to, zero will also be equal irrespective of the magnitude of the initial voltage. Therefore, line 2 will discharge fully in time T .

50. Magnetic vector potential

$$\vec{A} = \mu \iiint \frac{dv}{r} = \frac{\mu I}{4\pi R}$$

For current element $I \cdot dl$

$$\vec{A} = \frac{\mu I \cdot dl}{4\pi R}$$

51. At boundary

$$E_{n1} = E_{n2}$$

If one medium is conductor then $E_{n1} = 0$

59. For a vector to represent a magnetic, its divergence should be zero.

$$\vec{A} = x\vec{i}_x + y\vec{i}_y + kz\vec{i}_z$$

Hence $\nabla \cdot \vec{A} = 1 + 1 + k = 2 + k$

But $\nabla \cdot \vec{A}$ should be zero. Hence $k = -2$

60. Reflection coefficient $K = \frac{Z_R - Z_0}{Z_R + Z_0}$

Where $Z_R = Z_0$ $K = 0$

and, Standing wave ratio, $S = \frac{1+|K|}{1-|K|} = 1$

62. $\oint_C d\vec{l}$ is always zero whatever may be the closed path C , because $d\vec{l}$ is an element of displacement (not of simply length) and around a closed path in starting at one point and reaching back over there, net displacement is zero and hence $\oint_C d\vec{l} = 0$

69. $F = \frac{Q_1 Q_2}{4\pi\epsilon R^2}$

71. Dipole moment $M_e = Q \cdot d$
 $= Q \cdot L$

72. Since potential or potential difference is defined as the amount of work done in carrying unit positive charge from 1 point to other, joule/, coulomb should be 'volt'.

76. Characteristic impedance of transmission

$$\text{line is given by } Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

79. Since the wave length in the guide is given by $\lambda = \frac{V}{f}$, it will be longer than the corresponding free space wave length.

80. Wave guide have cut off frequency which attenuate the low frequency. Hence wave guide is High Pass Filter.

82. Silsbee's Rule prevent the use of super conductors as coils for the production of strong magnetic fields.

83. Impedance inversion may be obtained with A quarter -wave line

84. The potential difference around a close path is zero

85. $\Delta^2 V = \rho_v / \epsilon$

if $\rho_v = 0 \Rightarrow \nabla^2 V = 0$

86. Equipotential surfaces about a pair of equal and opposite linear charges exist in what form Planes

$$88. Z_{in} = R_0 \left(\frac{Z_R + j R_0 \tan \beta L}{R_0 + j Z_R \tan \beta L} \right)$$

$$Z_{in} = R_0 \left(\frac{Z_R + j R_0 \tan (2\pi/\lambda) L}{R_0 + j Z_R \tan (2\pi/\lambda) L} \right)$$

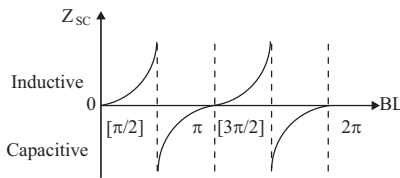
For short circuit line $Z_R \rightarrow 0$

$$Z_{in} = R_0 \left(\frac{0 + j R_0 \tan (2\pi/\lambda) L}{R_0 + j 0 \tan (2\pi/\lambda) L} \right)$$

$$Z_{in} = R_0 \left(\frac{j R_0 \tan (2\pi/\lambda) L}{R_0} \right)$$

$$Z_{in} = j R_0 \tan [2\pi/\lambda] L$$

So long as $\tan [2\pi/\lambda] L$ is positive, the impedance is purely inductive.



In present Case $L < [\lambda/4]$

$$B = [2\pi/\lambda]$$

$$BL < [2\pi/\lambda] \times [\lambda/4]$$

$$< [\pi/2]$$

There fore impedance is inductive.

91. If $Z_L = Z_0$ Then

$$K = \frac{Z_L - Z_0}{Z_L + Z_0} = 0$$

$$S = \frac{1 + |K|}{1 - |K|} = 1.$$

92. Maxwell equation in static EM field

$$\nabla \cdot D = -\rho_v; \quad \nabla \cdot B = 0$$

$$\nabla \times E = 0; \quad \nabla \times H = J$$

General Form Maxwell equation

$$\nabla \cdot D = -\rho_v; \quad \nabla \cdot B = 0$$

$$\nabla \times B = -[\partial B / \partial t]; \quad \nabla \times H = J + [\partial D / \partial t]$$

Above equation represent that the two divergence equation remain the same for time varying field but curl equation is modified.

$$93. \text{Skin depth } \delta = \sqrt{\frac{2}{\omega \mu \sigma}} \text{ and } \sigma = \frac{1}{\rho}$$

$$\delta \propto \sqrt{\frac{\rho}{2\pi f \mu}}.$$

94. Cylindrical and spherical Harmonics:

It was pointed out in earlier sections of this chapter that, except for a few special cases, solution Laplace's equation, subject to the appropriate boundary conditions, was in general a quite difficult problem. There is a group of problems

having a certain a certain symmetry that may be solved approximately by use of cylindrical of spherical harmonics. Because these function are also required for later uses in electromagnetic problems, they will be considered briefly here.

For those problems which can be set up in cylindrical co-ordinates, and for which there is no variation of the field in the z direction, Laplace's equation (38) may be written as

$$\frac{1}{\rho} \frac{\partial}{\partial \rho} \left(\rho \frac{\partial V}{\partial \rho} \right) + \frac{1}{\rho^2} \frac{\partial^2 V}{\partial \phi^2} = 0$$

The following set of possible solution of (65):

$$\rho; \frac{\cos \phi}{\rho}; \frac{\sin \phi}{\rho}; \frac{\cos 2\phi}{\rho^2}; \frac{\sin 2\phi}{\rho^2};$$

$$\frac{\cos 3\phi}{\rho^3}; \frac{\sin 3\phi}{\rho^3}; \dots$$

Replacing ρ^{-n} by ρ^{-n} gives a second set, viz:

$$\rho \cos \phi; \rho \sin \phi; \rho^2 \cos 2\phi; \rho^2 \sin 2\phi; \rho^3 \cos 3\phi; \rho^3 \sin 3\phi$$

These solution of Laplace's equation (65) are known as circular harmonic or cylindrical harmonics. These harmonic functions may be used to solve problem in which there is no variation of the field in the z-direction.

98. A Vector field whose components along two orthogonal axes are equal in amplitude and have a time phase difference of $\pm 90^\circ$ has constant magnitude and rotates so that the top of the vector traces a circle i.e., the field is circularly polarized

$$E_x = E_{xm} \sin \omega t; \quad E_y = E_{ym} \cos \omega t$$

$$\text{If } E_{xm} = E_{ym} = E_m \text{ then } E_x^2 + E_y^2 = E_m^2$$

It implies $x^2 + y^2 = c^2$ a circle.

100. Due to Dipole, the Electric potential at

$$\text{distance } r \text{ is given by } V = \frac{Q \cdot d \cos \theta}{4\pi \epsilon_0 r^2}$$

where,

Q = Charge

d = distance between Charge

θ = Angle between dipole axis and distance vector r

r = distance of Point where we define potential V w.r.t to center of distance between dipole.

Electric field at r distance is given by two component, i.e., one in r direction E_r and i.e., $E = E_r \hat{a}_r + E_{\theta} \hat{a}_{\theta}$, one in Q direction

$$E_r = \frac{Qd \cos \theta}{2\pi \epsilon_0 r^3} \text{ and } E_{\theta} = \frac{Qd \sin \theta}{4\pi \epsilon_0 r^3}.$$

LEVEL 2

$$1. \vec{F} = Q(\vec{V} \times \vec{B})$$

	$\vec{a}_x$	$\vec{a}_y$	$\vec{a}_z$
$\vec{B}$	1	2	-4
$\vec{V}$	3	-1	2

$$\begin{aligned} \vec{V} \times \vec{B} &= \begin{vmatrix} (4-4)\vec{a}_x + (-12-2)\vec{a}_y \\ \vec{a}_y + (-1-6)\vec{a}_z \end{vmatrix}_{V_o} \\ &= (14\vec{a}_y + 7\vec{a}_z)_{V_o} \end{aligned}$$

$$E = \frac{F}{Q} = -V_o(14\vec{a}_y + 7\vec{a}_z)$$

$$2. v = \frac{1}{\mu \epsilon}$$

$$\frac{c}{\sqrt{\epsilon_r}} = \frac{c}{\sqrt{4}} = \frac{c}{2}; \quad \frac{c}{c/2} = 2$$

$$4. f_c = \frac{3 \times 10^8}{2} \sqrt{\frac{m}{a^2} + \frac{m}{b^2}}$$

$$\begin{aligned} TE_{01} &= 1.5 \times 10^8 \sqrt{\frac{0}{(0.07)^2} + \frac{1}{(0.035)^2}} \\ &= \frac{5}{0.035} = 4.285 \end{aligned}$$

$$T_E = \frac{1.5 \times 10^8}{0.07} = 3.142$$

$$\frac{TE_{01}}{TE_{10}} = \frac{4.285}{2.142} = 2$$

6. At then interface we have the condition

$$Dn_1 - Dn_2 = \rho_s$$

$$\text{or } 1\epsilon_0 \epsilon_{n1} \epsilon_{n1} - \epsilon_0 \epsilon_{n2} \epsilon_{n2} = \rho_s$$

$$\text{or } 1\epsilon_0 [1 \times 1 - 2 \times 2] = \rho_s$$

$$\text{or } \rho_s = -3\epsilon_0$$

$$8. \vec{D} = \epsilon_0 \vec{E} + \vec{P}$$

$$\vec{P} = \vec{D} - \epsilon_0 \vec{E}$$

$$= \vec{D} - \frac{\epsilon_0 \epsilon_r \vec{E}}{\epsilon_r} = \vec{D} - \frac{\vec{D}}{\epsilon_r}$$

$$= \vec{D} \left(1 - \frac{1}{\epsilon_r} \right) = 1 \left(1 - \frac{1}{5} \right) = \frac{4}{5} = 0.8$$

9. Area of the loop, $A = \pi r^2$

Flux linking the area, $\phi = B \times \pi r^2$

emf induced = rate of change of flux link-

$$\text{age} = \frac{d\phi}{dt}$$

$$e(t) = \frac{d}{dt} (B \pi r^2) = B \pi 2r \left(\frac{dr}{dt} \right)$$

When $B = 0.1 T$, $r = 2 m$, and

$$\frac{dr}{dt} = 2 \text{ m/s}$$

$$e = 0.1 \times \pi \times 2 \times 2 \times 2 = 0.08 \pi V$$

$$10. F = \frac{Q_1 Q_2}{4\pi\epsilon r^2}$$

Force does not depend on the body on which charge is placed

$$13. \text{ Power carried by a wave } \mu E^2 \text{ or } H^2.$$

Or power, $P = KE^2$

$$\text{Then for incident wave, } E = \sqrt{\frac{P}{K}} = \sqrt{\frac{1}{K}}$$

$$\text{Reflection coefficient} = \frac{1}{2}$$

Therefore Transmission coefficient

$$= 1 - \frac{1}{3} = \frac{2}{3}$$

Therefore Transmission electric field

$$= \frac{2}{3} E = \frac{2}{3} \sqrt{\frac{1}{K}}$$

Power transmitted or absorbed by the load,

$$P_L = KE_L^2$$

$$K \frac{4}{9} \frac{1}{K} = \frac{4}{9} W$$

$$14. D = 1 \text{ m}, R = \frac{1}{2} \text{ m}$$

$$\text{Magnetic field density, } B = \frac{\mu_o I}{2R}$$

Then, Magnetic field intensity

$$H = \frac{I}{2R} = \frac{2}{2 \times \frac{1}{2}} = 2 \text{ A/m.}$$

15. A uniform plane wave traveling in a perfect dielectric is incident normally on the surface of perfect conductor. Then standing wave is set up in the dielectric.

16. The heat dissipated is maximum when $R = r = 4 \text{ ohm}$.

$$\text{Thus, } I = \frac{24}{4+4} = 3A$$

Thus, the current will be $\frac{I}{2} = 1.5A$ when

$$\text{the total resistance, } R_T = \frac{24}{1.5} = 16 \text{ ohm}$$

$$\text{Hence, } R = R_T - r = 16 - 4 = 12 \text{ ohm}$$

17. Force experienced by moving charge Q in magnetic field with velocity V is given by the Lorentz force i.e.,

$$\vec{F} = Q(\vec{V} \times \vec{B}) \rightarrow$$

The force experienced by unit charge is called field intensity.

$$\vec{E} = -(\vec{V} \times \vec{B})$$

$$|\vec{E}| = (E_x^2 + E_y^2 + E_z^2)^{1/2}$$

In Present case

$$\vec{E} = -(V \times B) = -(2i + 3j) \times (i - 2j)$$

$$= -[0 + 4k - 3k + 0 + j - 2i]$$

$$= -[k + j - 2i]$$

$$|E| = \sqrt{(1^2 + 1^2 + 2^2)} = \sqrt{6} \text{ Volt/m}$$

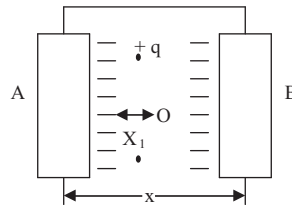
$$|E| = \sqrt{1^2 + 1^2 + 2^2} = \sqrt{6} \text{ volt/m}$$

Potential difference across 1 m length

$$E = [V/d] \quad ; \quad V = E \cdot d$$

$$= 6 \text{ volt}$$

18. Referring the adjacent diagram.



The charge $+q$ would induce charges of opposite nature at the inner surfaces of the parallel plates, and a larger amount would be produced on the nearer plate. If it is too close to A , most of the charges would be induced on A and presence of B would be insignificant. However, the total induced charge must be and opposite to the inducing charge $+q$ and hence answer is $-q$.

19. Pressure P = Electric energy density

$$= \frac{1}{2} \epsilon E^2 = \frac{1}{2} \cdot \frac{D^2}{\epsilon}$$

Now at conductor surface, surface-charge density s_s and D are equal just outside i.e.,

$$D_{n1} - D_{n1} = s_s$$

$$D_{n1} = s_s$$

$$D = s$$

$$\therefore P = \frac{1}{2} \frac{\sigma^2}{\epsilon}$$

20. Reflection Coefficient between the load $Z_L = (75 \text{ ohm})$ and the feed coaxial line of charged impedance $Z_0 = 50 \text{ ohm}$, is

$$K = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$K = \frac{75 - 50}{75 + 50} = \frac{1}{5}$$

Voltage Standing Wave Ratio,

$$S = \frac{1 + |K|}{1 - |K|} = \frac{1 + (1/5)}{1 - (1/5)} = \frac{3}{2}$$

$$22. [B] = \frac{[\phi]}{[A]} = \frac{[\text{emf}][\text{time}]}{[\text{area}]}$$

$$= \frac{[I^{-1} ML^2 T^{-3}][T]}{[L^2]}$$

$$= [I^{-1} ML^2] = [ML^2 Q^{-1}]$$

$$23. \eta = \sqrt{\frac{\mu_o}{\epsilon_o}} = 120\pi$$

$$\vec{P} = \vec{E} \times \vec{H} = \eta H^2 \sin^2(\omega t - By) \hat{a}_y$$

$$P_{av} = \frac{1}{T} \int_0^T P dt = \frac{\eta H^2}{2} \hat{a}_y = \frac{120\pi \times 0.01}{2} \hat{a}_y$$

$$= -0.6 \hat{a}_y$$

24. By Faraday's 2nd law, EMF induced is given by

$$e = -N \frac{d\phi}{dt} = -(3t^2 - 2) \Big|_{t=4} \times 100$$

$$= -4.6 V$$

25. Velocity of EM wave in any medium is given by

$$v = \frac{1}{\sqrt{\mu\epsilon}} = \frac{3 \times 10^8}{\sqrt{\mu_r \epsilon_r}} = \frac{3 \times 10^8}{\sqrt{4.5 \times 2}}$$

$$= \frac{3 \times 10^8}{\sqrt{9}} = 10^8 \text{ m/s}$$

$$26. K = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{-10 + 30j}{90 + 30j}$$

$$|K| = \frac{\sqrt{10}}{\sqrt{90}} = \frac{1}{3}$$

$$S = \frac{1 + |K|}{1 - |K|} = \frac{1 + \frac{1}{3}}{1 - \frac{1}{3}} = 2$$

$$27. \epsilon_1 = 1, \epsilon_2 = 2.7$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\frac{n_1}{n_2} = \sqrt{\frac{\epsilon_2}{\epsilon_1}} ; n_2 = \frac{1}{\sqrt{\epsilon_2}}$$

$$\text{or } \sin \theta_2 = \frac{1}{\sqrt{\epsilon_2}} \sin 30^\circ = 0.3$$

$$\theta_2 = 18$$

$$28. \oint_c \vec{H} \cdot d\vec{l} = i$$

$$\text{Or } H \times 2\pi r = I \times \frac{\pi r^2}{\pi R^2} \therefore H = \frac{Ir}{2\pi R^2}$$

29. For dc, L is Short circuit

$$R = 5\Omega, L = 0.4 H, I = \frac{50}{5} = 10 A$$

$$W_m = \frac{1}{2} LI^2 = \frac{1}{2} \times (0.4) \times (10)^2 = 20 J$$

30. $q = CV$

$$\text{Or } i = C \frac{dv}{dt}$$

$$\text{Or } V_c = \frac{1}{C} \int i dt = \frac{2 \times 10^{-6} \times 6}{3 \times 10^{-6}} = 4 V$$

$$31. Z_1 = \sqrt{Z_0 R_L} \\ = \sqrt{400 \times 25} = 100 \Omega$$

$$32. W = \frac{1}{2} CV^2 \text{ before immersion}$$

$$W_1 = \frac{1}{2} \times 0.005 \times 10^{-6} \times 25 \times 10^4 \\ = 625 \times 10^{-4} J \text{ after immersion,}$$

$$C_2 = \epsilon C_1 \text{ and } V_2 = \frac{V_1}{\epsilon}$$

$$\text{Therefore, } W_2 = \frac{1}{2} C_2 V_2^2 \\ = \frac{1}{2} \frac{C_1 V_1^2}{\epsilon} = 250 \times 10^{-4} J$$

$$33. \text{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} = 2$$

$$\text{or } |\Gamma| = \frac{1}{3} = 0.33$$

$$34. Z_1 = \sqrt{Z_1 Z_2} = \sqrt{200 \times 50} = 100 \Omega$$

$$35. W = \frac{Q_1 Q_2}{4\pi\epsilon_0 \sqrt{(3)^2 + (2)^2 + (6)^2}} = 5.14 \text{ mJ}$$

$$36. \text{Magnetic dipole moment} = i \cdot \bar{A} \\ = 0.01 \times (20 \times 20) \hat{a}_z \\ = 4 \hat{a}_z$$

$$37. E = E_0 \sin \omega t$$

Conduction current through resistance μ
 $E = E_0 \sin \omega t$

Displacement current through capacitor

$$i = c \frac{dv}{dy} \mu \frac{\partial E}{\partial t} = \omega E_0 \cos \omega t \\ = \omega E_0 \sin (\omega t + \pi/2)$$

$$38. e^{-\alpha x} = 0.1$$

$$\text{or, } x = \frac{\ell n 10}{\alpha}$$

as, $\frac{\sigma}{\omega \epsilon} \gg 1$, so sea water is acting as a good conductor

$$\text{Therefore } \alpha = \sqrt{\frac{\omega \mu \sigma}{2}} \\ = \sqrt{\frac{2\pi \times 25 \times 10^3 \times 4\pi \times 10^{-7} \times 5}{2}} = 0.7$$

$$\text{Therefore, } x = 3.22 \text{ m.}$$

$$39. \omega = 6\pi \times 10^8$$

$$\text{Phase constant } \beta = \frac{\omega}{v}$$

$$\text{Where, } V = \frac{1}{\sqrt{\mu \epsilon}} = \frac{1}{\sqrt{\mu_0 81 \epsilon_0}} = \frac{3 \times 10^8}{\sqrt{81}}$$

$$\text{Therefore, } \beta = \frac{\omega}{v} = \frac{6\pi \times 10^8}{3 \times 10^8} \times 9 \\ = 18\pi \text{ rad/m}$$

$$40. C = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \text{ ----- For free space}$$

$$V = \frac{1}{\sqrt{\mu \epsilon}}; \quad v_p = \frac{c}{\sqrt{\epsilon_r}} = 0.4 \times c$$

$$\text{Therefore, } \epsilon_r = (2.5)^2 = 6.25$$

41. **Gauss's law:** It states that the total displacement or electric flux enclosed by a surface surrounding charges is equal to the amount of charge enclosed.

$$\oint \vec{D} \cdot d\vec{s} = Q = \iiint_V \nabla \cdot \vec{D} dv$$

Gauss's law in differential form or Maxwell's 1 equation.

$$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0} \text{ or } \nabla \cdot \vec{D} = \rho$$

$$\rho = \nabla \cdot \vec{D} \text{ and } \vec{D} = \epsilon_0 \vec{E}$$

$$\vec{E} = -\nabla V = -\left[\frac{\partial V}{\partial x} \hat{a}_x + \frac{\partial V}{\partial y} \hat{a}_y \right] \\ = -[60x^2 + 40y^3]$$

$$\text{Therefore, } \rho = -\epsilon_0 [60x^2 + 40y^3]$$

At [2, 0]

$$\rho = -\epsilon_0 [60 \times 2^2 + 0] = -240 \epsilon_0$$

$$42. \left| \frac{E_r}{E_\theta} \right| = \left| \frac{\sin[N\pi(d/\lambda) \cdot \sin\theta]}{\sin[\pi(d/\lambda) \cdot \sin\theta]} \right|$$

Condition for presence of grating lobes,

$$\pi \left(\frac{d}{\lambda} \right) \sin \theta = \pm n\pi \text{ where } n = 1, 2, 3 \dots$$

So, for no grating lobes,

$$d < \lambda$$

$$43. H = \frac{I}{2\pi r} \hat{a}_\phi; \text{ at } (0, 5, 0)$$

$$H = \frac{10\pi}{2\pi \cdot 5} \cdot \hat{a}_x = \hat{a}_x A/m$$

$$44. Z_0^2 = Z_{sc} \cdot Z_{oc}$$

$$\bullet \quad Z_c = \sqrt{Z_1 Z_2}$$

45. Directivity or Directive gain

$$= \frac{\text{maximum power density}}{\text{average value of power density over a sphere}} \\ \therefore \text{maximum power density directivity} \times A_p P_D \\ = \frac{30 \times 7.5 \times 10^3}{4\pi r^2} = \frac{(30) 7.5 \times 10^3}{4\pi (40 \times 10^3)^2} W/m^2$$

$$46. \Rightarrow 16 + 4K + 4K = 0$$

$$\Rightarrow K = -2$$

Second Method

$\vec{E}$ is perpendicular to the direction of the uniform plane wave, so their dot product = 0

$$\vec{E}_x \cdot \vec{E}_y = 0$$

$$\therefore (4\hat{a}_x - 2\hat{a}_y - \hat{a}_z) \cdot (4\hat{a}_x - 2K\hat{a}_y + 4K\hat{a}_z) = 0$$

$$\Rightarrow 16 + 4K + 4K = 0$$

$$\Rightarrow K = -2$$

47. From uniform plane wave equation

$$\frac{\partial E_x}{\partial z} = -\mu_0 \frac{\partial H_y}{\partial t} = -\frac{\partial B}{\partial t}$$

$$\Rightarrow \frac{\partial E_x}{\partial z} = +B_0 \omega z \sin \omega t$$

$$\Rightarrow E_x = \frac{1}{2} B_0 z^2 \omega \sin \omega t$$

$$48. C = \frac{\epsilon A}{d}$$

$$Q = C \cdot V = \frac{2\epsilon_0 \cdot 5 \times 10^{-4}}{5 \times 10^{-3}} \cdot V$$

$$\Rightarrow I = \frac{dQ}{dt} = C \cdot \frac{dv}{dt} \\ = 0.2 \epsilon_0 \times 50 \times 1000 \times \cos 10^3 t \\ = \epsilon_0 10^4 \cos 10^3 t$$

49. Torque = Dipole moment $\times$ Electric field
 $= Q \cdot d \times E$

$$= (1 \times 10^{-6} \times 2 \times 10^{-3} \hat{a}_z) \times 10^{-3}$$

$$(2\hat{a}_x - 2\hat{a}_y - 2\hat{a}_z)$$

$$= 2 \times 10^{-6} (\hat{a}_z \times (2\hat{a}_x - \hat{a}_y - 2\hat{a}_z))$$

$$= 2 \times 10^{-6} (2\hat{a}_y + \hat{a}_x + 0)$$

$$= 2 \times 10^{-6} (\hat{a}_x + 2\hat{a}_y) N \cdot m$$

$$50. D_{N1} - D_{N2} = \rho_s$$

$D_{N1} = D_{N2}$ as ρ_s (at boundary) is zero

$$\therefore \epsilon_1 E_{N1} = E_{N2} \epsilon_1$$

$$\therefore E_{N2} = 4\hat{a}_z \text{ kV/m}$$

$$\therefore V = E_{N1} 10^{-3} + E_{N2} \cdot 10^{-3} = 14 V$$

$$52. \nabla \cdot B = 0$$

$$\left(\frac{\partial}{\partial x} \hat{a}_x + \frac{\partial}{\partial y} \hat{a}_y + \frac{\partial}{\partial z} \hat{a}_z \right) \cdot$$

$$(x^2 \hat{a}_x - xy \hat{a}_y - Kxz \hat{a}_z) = 0$$

$$x \cdot (1 - K) = 0 \Rightarrow K = 1$$

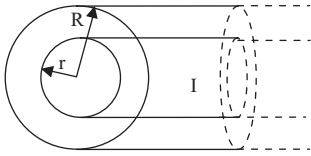
53. $B_{N1} = B_{N2}$ and $H_{r1} = H_{r2}$

$$\Rightarrow B_{N2} = \mu_o \cdot 6H_{N2} = 8$$

$$H_{r2} = \frac{B_{r1}}{\mu_o \cdot 4} = \frac{5}{\mu_o \cdot 4}$$

$$\Rightarrow H(z < 0) = \frac{5\hat{a}_x}{4\mu_o} + \frac{5\hat{a}_z}{6\mu_o} \text{ mA/m}$$

54. BY applying Ampere's law



$$\oint \vec{H} \cdot d\vec{l} = I_{enc}$$

$$\Rightarrow H \cdot 2\pi r = 1 \cdot \frac{\pi r^2}{\pi R^2}$$

$$\Rightarrow H = \frac{I r}{2\pi R^2}$$

Second Method

In general $\vec{H} = \frac{I}{2\pi r} \hat{a}_\phi$

Current enclosed at distance or i.e. I'

$$= \frac{I}{\pi R^2} \times \pi r^2 = \frac{I r^2}{R^2}$$

$$H(r) = \frac{I'}{2\pi r} \hat{a}_\phi = \frac{1 r^2}{2\pi r R^2} = \frac{I r}{2\pi R^2} \hat{a}_\phi$$

55. $E \propto \frac{1}{\epsilon}$

$$\frac{E_{air}}{E_{dielect}} = \frac{\epsilon_{dielect}}{\epsilon_{air}} = 5$$

58. Intrinsic impedance of medium is given by

$$\eta = 377 \sqrt{\frac{\mu_r}{\epsilon_r}}$$

$$\eta_1 = 377 \sqrt{\frac{2}{8}} = \frac{377}{2} = 188 \Omega$$

$$\eta_2 = 377 \sqrt{\frac{9}{1}} = 377 \times 3 = 1131 \Omega$$

$$\eta_3 = 377 \sqrt{\frac{4}{1}} = 754 \Omega$$

59. $\eta_1 = Z$, $\eta_2 = 2Z$

$$\frac{E_i}{E_r} = \frac{\eta_1 + \eta_2}{2\eta_2} = \frac{Z + 2Z}{2 \cdot 2Z} = \frac{3}{4}$$

$$\frac{H_i}{H_r} = \frac{\eta_1 + \eta_2}{2\eta_1} = \frac{3Z}{2Z} = \frac{3}{2}$$

60. $E = \frac{V}{d}$

62. Total flux linkage $\lambda = N\phi$

$$\text{Induced emf } e = -\frac{d\lambda}{dt}$$

$$= -\frac{d}{dt} (100 \times (t^2 - 2t) \times (10^{-3}))$$

$$= -0.1(3t^2 - 2)$$

$$e(at t = 2s) = -0.1(12 - 2) = -1V$$

63. $\oint_S \vec{B} \cdot d\vec{s} = 0$

or $\oint_S \vec{B} \cdot d\vec{s} = \oint_V (\nabla \cdot \vec{B}) dv$

For solenoid field, $\nabla \cdot \vec{B} = 0$

Then $\oint_S \vec{B} \cdot d\vec{s} = 0$

This is due to (nonexistence of monopole)

66. Observation of the phase $\omega t - \beta z$, shows that the direction of propagation is $+z$. Hence $E \times H$ must also be in the $+z$ direction and E must have the direction $-\hat{a}_y$.

$$\frac{E_y}{H_x} = 377 \Omega$$

$$\Rightarrow E(z, t) = -37.7 \cos(4 \times 10^7 t - \beta z) \hat{a}_y$$

67. $P_{av} = [\vec{E} \times \vec{H}] \cdot d\vec{s}$

$$= \frac{250}{12\pi} \langle \cos^2(\omega t - \beta z) \rangle \pi r^2$$

As a verage value of

$$\left[\cos^2(\omega t - \beta z) = \frac{1}{2} \right]$$

$$\therefore P_{av} = \frac{250}{12\pi} \cdot \frac{1}{2} \cdot \pi \times 24$$

Second Method

$$P_{avg} = \frac{1}{2} R_e(E \times H^*) \cdot \pi r^2 \hat{a}_z W$$

$$= \frac{1}{2} \times 50 \times \frac{5}{12\pi} \times \pi \times 24 = 250 W$$

68. $\frac{J_C}{J_D} = \frac{\sigma}{\omega \epsilon} = \frac{I_C}{I_D} \cdot \frac{A}{A}$

$$\therefore I_D = I_C \cdot \frac{\omega \epsilon}{\sigma} = 1 \times \frac{2 \times \pi \times 50 \times 10^{-9}}{5.8 \times 10 \times 36\pi}$$

$$= 4.8 \times 10^{-11} A$$

69. $Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$ and

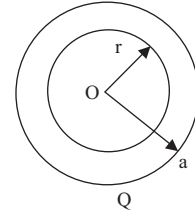
$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

$$\frac{R + j\omega L}{\gamma} = \frac{R + j\omega L}{\sqrt{(R + j\omega L)(G + j\omega C)}}$$

$$= \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}}$$

70. $\nabla \times E = 0$ for conservative electric field.

72. The potential at $r = b$,



$$V_b = V_a - V_\infty$$

$$= V_a - V_\infty + V_b - V_a$$

$$= -\int_a^r \frac{Q}{4\pi\epsilon_0 r^2} dr - \int_a^b \frac{Qr}{4\pi\epsilon_0 a^3} dr$$

Second method

$$V_{ab} = -\int_a^b \frac{Q_{enclosed}}{4\pi\epsilon_0 r^2} dr, \text{ where } b < a$$

$$\text{as } Q_{enclosed} = \frac{Q_{total}}{4} \cdot \frac{4}{\pi a^3} \pi r^3$$

$$\therefore V_{ab} = -\int_a^b \frac{Q_{total}}{4\pi\epsilon_0 a^3} dr$$

$$\therefore V_b - V_\infty = V_b - 0 = V_a - V_\infty + V_b - V_a$$

$$\therefore V_b = -\int_\infty^a \frac{Q}{4\pi\epsilon_0 r^2} dr - \int_a^b \frac{Qr}{4\pi\epsilon_0 a^3} dr$$

75. By Stoke's law, $\oint_S (\nabla \times \vec{E}) \cdot d\vec{s} = \oint \vec{E} \cdot d\vec{l}$

Then, $\oint \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \oint \vec{B} \cdot d\vec{s}$

76. Propagation constant γ

$$= (\alpha + j\beta) = (0.1 + j2)$$

77. Skin depth, $\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$

or $\delta \propto \frac{1}{\sqrt{\sigma}}$

78. $|\vec{E}_x| = |\vec{E}_y|$ and angle between $\vec{E}_x$ and $\vec{E}_y$ is 90° then the polarization is circular.

79. All the three statement are correct.

$$Z_s = Z_0 \frac{Z_L + j Z_0 \tan \beta l}{Z_0 + j Z_L \tan \beta l}$$

$$Z_s = j Z_0 \tan \beta l$$

$$[Z_L = 0 \text{ for short circular}]$$

81. Reflection coefficient,

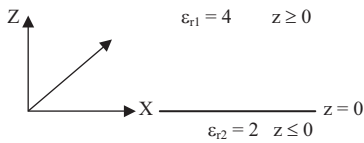
$$\tau = \frac{Z_L - Z_0}{Z_0 + Z_L} = \frac{900 - 600}{900 + 600} = \frac{3}{15} = 0.2$$

82. Force experienced by current carrying conductor placed in magnetic field is given by

$$\begin{aligned}
 dF &= \vec{I} \cdot d\vec{\ell} \times \vec{B} \\
 &= (\vec{I} \times \vec{B}) d\ell \\
 F &= \int (\vec{I} \times \vec{B}) d\ell \\
 &= 5(\vec{a}_z) \times (3\vec{a}_x + 4\vec{a}_y) \\
 &= -20\vec{a}_x + 15\vec{a}_y \text{ N/m}
 \end{aligned}$$

$$\begin{aligned}
 83. \quad E &= \frac{\rho_z}{2\epsilon_0} (-\vec{a}_z) \\
 &= \frac{20 \times 10^{-9} \times 4\pi \times 9 \times 10^9}{2 \times 1} (-\vec{a}_z) \\
 &= 360\pi \hat{a}_z \text{ V/m}
 \end{aligned}$$

84.



$$D_{n1} - D_{n2} = \rho_s \text{ (surface charge density)}$$

$$D_{n1} = D_{n2} \text{ (in charge-free region)}$$

$$\epsilon_0 \epsilon_{r1} E_{z1} = \epsilon_0 \epsilon_{r2} E_{z2}$$

$$\therefore 4 \times 3 = 2 \times E_{z2}$$

$$\therefore E_{z2} = 6 \hat{a}_z$$

85. Polarization

$$P = \vec{D} - \epsilon \vec{E}$$

$$= \vec{D} - \frac{\vec{D}}{\epsilon_r}$$

$$= \left[1 - \frac{1}{\epsilon_r} \right]$$

$$= \frac{4}{5} = 0.8$$

86. Wave equation in form of vector potential and

Max well equation for time varying field

$$\nabla \times H = J + \epsilon \frac{\partial E}{\partial t} \quad (1)$$

$$\nabla \times \vec{E} = -\mu \frac{\partial H}{\partial t} \quad (2)$$

$$\nabla \cdot E = \frac{\rho}{\epsilon} \quad (3)$$

$$\nabla H = 0 \quad (4)$$

From continuity equation

$$\nabla \cdot J = -\frac{\partial \rho}{\partial t} \quad (5)$$

Equation (4) is satisfied if H is represented as curl of some vector. This leads to the following definition for vector potential A .

$$\mu H = \nabla \times A \quad (6)$$

From equation (2) and (6)

$$\nabla \cdot \vec{E} = -\frac{\mu \partial H}{\partial t} = -\nabla \times \frac{\partial A}{\partial t}$$

$$\nabla \times \left(\vec{E} + \frac{\partial A}{\partial t} \right) = 0 \quad (7)$$

Equation (7) is satisfied if $\left(\vec{E} + \frac{\partial A}{\partial t} \right)$ is

represented as the gradient of scalar, setting

 $\left(\vec{E} + \frac{\partial A}{\partial t} \right)$ equal to $-\nabla V$ define the

scalar potential V in such a way that for slowly varying field it is identical to the scalar potential.

Then

$$E + \frac{\partial A}{\partial t} = -\nabla V$$

$$E = -\nabla V - \frac{\partial A}{\partial t}$$

From the seven equation we reach to

$$\nabla^2 \vec{A} \mu \epsilon - \frac{\partial^2 \vec{A}}{\partial t^2} = -\mu \vec{J} \text{ and}$$

$$\nabla^2 V - \mu \epsilon \frac{\partial^2 V}{\partial t^2} = \frac{-\rho}{\epsilon}$$

$$\begin{aligned}
 87. \quad \eta &= \sqrt{\frac{\mu}{\epsilon}} = \sqrt{\frac{\mu_0 \mu_r}{\epsilon_0 \epsilon_r}} = \sqrt{\frac{\mu_r}{\epsilon_r}} \cdot \sqrt{\frac{\mu_0}{\epsilon_0}} \\
 &= \eta_0 \sqrt{\frac{\mu_r}{\epsilon_r}}
 \end{aligned}$$

$$\text{or, } \eta = 120 \pi \sqrt{\frac{1}{\epsilon_r}} = 60 \pi$$

$$\text{or, } \epsilon_r = 4$$

$$88. \quad l = 50 \text{ cm} = \frac{1}{2} \text{ m}$$

$$f \lambda = c = \frac{1}{\sqrt{LC}}$$

$$\text{or } 30 \times 10^6 \times \lambda = \frac{1}{\sqrt{10 \times 10^{-6} \times 40 \times 10^{-12}}}$$

$$\text{or, } 30 \times 10^6 \times \lambda = \frac{10^9}{20}$$

$$\Rightarrow \lambda = \frac{5}{3}$$

$$B = \frac{2\pi}{\lambda}$$

$$\begin{aligned}
 \therefore \beta \ell &= \frac{2\pi}{\lambda} \ell = \frac{2\pi}{5} \times 3 \times \frac{1}{2} \\
 &= \frac{6\pi}{10} = \frac{6 \times 180}{10} = 108
 \end{aligned}$$

$$90. \quad \tau = -\frac{Z_R - Z_0}{Z_R + Z_0} = \frac{23 - 20}{20 - 20} = \frac{1}{2}$$

$$91. \quad Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \text{ and}$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

$$\begin{aligned}
 \frac{R + j\omega L}{\gamma} &= \frac{R + j\omega L}{\sqrt{(R + j\omega L)(G + j\omega C)}} \\
 &= \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}}
 \end{aligned}$$

92. Write poisson equation put $\rho = 0$ Result Laplace equation.94. Magnetic mono poles one not physically possible as per Gauss's law i.e., $\nabla \cdot \vec{B} = 0$

95. Given

$$r = a$$

$$\oint_s \vec{D} \cdot d\vec{s} = \int_v \rho_v dv$$

$$\Rightarrow D \propto 4\pi r^2 = \rho_v \cdot \frac{4}{3} \pi r^3$$

$$D = \frac{a}{3} \rho_v \hat{r} \text{ C/m}^2$$

$$98. \quad \frac{1}{c} = \frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_3} + \frac{1}{c_4} + \frac{1}{c_5} + \frac{1}{c_6} \text{ as}$$

$$c_1 > c_2 > c_3 > c_4 > c_5 > c_6$$

$$\text{Hence } c \equiv c_6$$

$$99. \quad H = \frac{1}{2} \times 30 \hat{k} \times j$$

$$H = -15 \hat{i} \text{ mA/m}$$

$$100. \quad I^2 R = I^2 \cdot \frac{l}{\sigma} \cdot \frac{i}{\pi b^2}$$

 $\therefore$ Poynting vector (W/m²) on the surface

$$\begin{aligned}
 &= \frac{I^2}{\sigma \pi b^2} \cdot \frac{l}{2\pi b l} (\hat{k} \times \hat{j}) \\
 &= -\frac{I^2}{2\sigma \pi^2 b^3} \hat{i} \text{ (W/m}^2\text{)}
 \end{aligned}$$

LEVEL 3

1. Since it is a perfect conductor

$$\text{Then } E_{xr} = -E'_x$$

2. Input impedance of transmission line for finite length is given by

$$z_{in} = z_o \left(\frac{Z_L + Z_o \tanh \gamma \cdot \ell}{Z_L + Z_o \tanh \gamma \cdot \ell} \right) \text{ (lossy)}$$

Where $g = a + jb$ and ℓ = length of transmission line. For a lossless line, $a = ja$; $\tan h j b \ell = j \tan b \ell$ and $Z_o = R_o$ then above equation becomes.

$$z_{in} = z_o \left(\frac{Z_L + Z_o \tanh \beta \cdot \ell}{Z_o + Z_L \tanh \beta \cdot \ell} \right) \text{ (lossless)}$$

Showing that the input impedance varies periodically with distance ℓ from the

12. Reflection coefficient $= (Z_L - Z_o)/(Z_L + Z_o)$

$$\text{Or } = [(300 - 300)/(300 + 300)] = 0$$

Hence line is perfectly matched

$$\begin{aligned} 13. \quad \bar{H} &= \frac{I}{2\pi d} \bar{Y} + \frac{I}{2\pi d} \bar{Y} \\ &= \frac{I}{\pi d} \bar{Y} \end{aligned}$$

$$14. \quad L = \frac{\mu_o \ell n}{\pi} \frac{d}{a}$$

Where, d – separation

a – radius

$$\begin{aligned} 15. \quad V_{PQ} &= \frac{q}{4\pi\epsilon_o} \left(\frac{1}{r_1} - \frac{1}{r_2} \right) = \frac{q}{4\pi\epsilon_o} \left(\frac{1}{40} - \frac{1}{20} \right) \\ &= \frac{10^{-9}}{4\pi \times 8.85 \times 10^{-12}} \left(\frac{20 - 40}{40 \times 20} \right) \frac{10^{-3}}{10^{-6}} \\ &= -0.002248 \times 10^5 = -225 \text{ V} \end{aligned}$$

16. When capacitors formed by two layer of dielectric i.e., two capacitor are in series, the, equivalent capacitance is given by

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} = \frac{\frac{\epsilon_o \epsilon_{r1} A}{d_1} + \frac{\epsilon_o \epsilon_{r2} A}{d_2}}{\frac{\epsilon_o \epsilon_{r1} A}{d_1} + \frac{\epsilon_o \epsilon_{r2} A}{d_2}}$$

$$\begin{aligned} C_{eq} &= \frac{\epsilon_o^2 A^2 \epsilon_{r1} \epsilon_{r2}}{\epsilon_o A [\epsilon_{r1} d_2 + \epsilon_{r2} d_1]} \\ &= \frac{\epsilon_o A \epsilon_{r1} \epsilon_{r2}}{\epsilon_{r1} d_2 + \epsilon_{r2} d_1} \end{aligned}$$

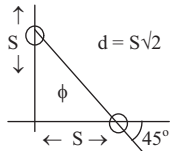
In present case, $\epsilon_{r1} = 4$, $d_1 = 6$ mm;

$\epsilon_{r2} = 2$, $d_2 = 8$ mm

$$\begin{aligned} C_{eq} &= \frac{(8.854 \times 10^{-12}) \times (400 \times 10^{-3})^2 \times 4 \times 2}{4 \times 8 \times 10^{-3} + 2 \times 6 \times 10^{-3}} \\ &= 257 \text{ pF.} \end{aligned}$$

17. Given that 2 similar antenna are placed in $\theta = [\pi/2]$ plane. Amplitude x citation is equal but 180 polarity difference.

Magnitude of far zone electric field strength of signal element ($\phi = 0$)



$$E_r = E_o \ddot{O}(1 + K^2 + 2K \cos \phi)$$

For equal magnitude, $K = 1$

Normalized array factor $= 2 |\cos [\phi/2]|$

Where, $\phi = bd \sin \theta \cos \phi + d$

$\theta = 90^\circ$; $d = \ddot{O}2 \text{ S}$; $\phi = 45^\circ$

$d = 180^\circ = \text{phase shift}$

$d = \text{Phase shift}$

$\theta = \text{angle of point where we find field w.r.t axis of array}$

$$\begin{aligned} 2 |\cos [\phi/2]| &= 2 \cos \frac{\beta d \sin \theta \cos \phi + \delta}{2} \\ &= 2 \cos \left(\frac{(2\pi/\lambda)(\sqrt{2})S \sin 90^\circ \cos 45^\circ + 180}{2} \right) \end{aligned}$$

$$= 2 \cos \left(\frac{2\pi}{\lambda.2} (\sqrt{2})S \times 1 \cdot \frac{1}{\sqrt{2}} + 90 \right)$$

$$= 2 \cos \left(\frac{\pi S}{\lambda} + 90 \right) = 2 \sin \left(\frac{\pi S}{\lambda} \right)$$

18. Signal picked up by received antenna may be increased by increasing either h_i or h_r .

20. The phase of current in antenna A lags behind that of B by $[\pi/2]$ radians

21. Signal picked up by receiving antenna may be increased by increasing either h_i or h_r .

23. $Z_R = 100 \text{ ohm}$, $Z_o = 50 \text{ ohm}$

Source resistance, $Z_s = 50 \text{ ohm}$

For maximum power transfer, the source should see an impedance of 50 ohm. This can be accomplished by selecting a proper length of the line, For a loss-less line of length L, the input impedance is

$$Z_{in} = R_o \left(\frac{Z_R + j R_o \tan \beta L}{R_o + j Z_R \tan \beta L} \right)$$

$$Z_{in} = R_o \left(\frac{Z_R + j R_o \tan (2\pi/\lambda) L}{R_o + j Z_R \tan (2\pi/\lambda) L} \right)$$

If $L = [l/8]$ and $Z_R = R_o$, then

$$Z_{in} = R_o \left(\frac{R_o + j R_o}{R_o + j R_o} \right)$$

$\therefore |Z_{in}| = R_o$ which is desired

For the given frequency,

$$\lambda = \frac{3 \times 10^8}{3 \times 10^6} = 10 \text{ m}$$

$$L = \left(\frac{\lambda}{8} \right) \left(\frac{10}{8} \right) = 1.25 \text{ m.}$$

24. Pressure, $P = \text{Electric energy density}$

$$= [1/2] e E^2$$

$$= [1/2] \cdot [D^2/\epsilon]$$

Now at **conductor surface**, surface-charge density s and D just outside are equal i.e., in boundary condition $D_{n1} - D_{n2} = s$

In conductor electric fields zero, therefore $D_n = s$

$$\therefore P = [1/2] \cdot [s^2/\epsilon] = s^2/2\epsilon.$$

25. **Reflection Coefficient** between the load $Z_R = (75 \text{ ohm})$ and the feed coaxial line of charged impedance $Z_o = 50 \text{ ohm}$ is

$$K = \frac{Z_R - Z_o}{Z_R + Z_o}; K = \frac{75 - 50}{75 + 50} = \frac{1}{5}$$

Voltage Standing Wave Ratio,

$$S = \frac{1 + |K|}{1 - |K|} = \frac{1 + (1/5)}{1 - (1/5)} = \frac{3}{2} = 1.5.$$

26. Characteristic resistance of the line should be, $R_o = \sqrt{50 \times 72} = 60 \text{ ohm}$

Now for an air field coaxial cable, the characteristic resistance, $R_o = 60 \ln [b/a]$ ohm, where b is the outer conductor diameter and a is the linear conductor diameter.

$$\text{Thus } 60 = 60 \ln [b/a] \Rightarrow e^{[b/a]} = 1$$

Hence $b = a \times e$ $b/a = e$

where $e = 2.718$

$$\therefore b = 27.18 \text{ mm.}$$

27. This problem can be solved directly in time domain or using phasors. We find H by making E and H satisfy Maxwell's four equations.

Let us solve this problem in time domain. It is evident that the Gauss's law for electric fields is satisfied; that is

$$\nabla \cdot E = \frac{\partial E_y}{\partial y} = 0$$

$$\nabla \cdot E = -\mu \frac{\partial H}{\partial t} \rightarrow H = -\frac{1}{\mu} \int (\nabla \times E) dt$$

$$\begin{aligned} \text{But, } \nabla \times E &= \begin{vmatrix} \hat{a}_x & \hat{a}_y & \hat{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 0 & E_y & 0 \end{vmatrix} \\ &= -\frac{\partial E_y}{\partial z} \hat{a}_x + \frac{\partial E_y}{\partial z} \hat{a}_x \end{aligned}$$

$$E = \frac{1}{c} \left[A \sin \omega t - \left(\frac{z}{c} \right) \right] \hat{a}_x$$

$$H = \frac{1/c}{\mu} \int (A \sin \omega t - (z/c)) \cdot \hat{a}_x dt$$

$$= -\frac{(1)}{c\mu} [A \cos \omega t - (z/c)] \hat{a}_z$$

$$= -\frac{\sqrt{\mu_o \epsilon_o}}{\mu} [A \cos \omega t - (z/c)] \hat{a}_z$$

$$= -\sqrt{\frac{\epsilon_o}{\mu_o}} [A \cos \omega t - (z/c)] \hat{a}_z.$$

28. $Z_o = \sqrt{Z_{sc} \cdot Z_{oc}} = \sqrt{5 \times 20} = 10 \Omega.$

$$29. \quad Z_o = \sqrt{L/C} = \sqrt{\frac{294 \times 10^{-6}}{60 \times 10^{-12}}} = 70 \Omega.$$

$$30. \quad \bar{D} = \epsilon_o \epsilon_r \bar{E} = \epsilon_o \bar{E} + \bar{P}$$

$$31. \quad K = \frac{Z_L - Z_o}{Z_L + Z_o}.$$

32. Propagation Constant

$$g = j + jB$$

$$= (R + j\omega L)(G + j\omega C)^{1/2}.$$

$$34. I = \frac{-dQ}{dt}$$

$$\text{But, } I = \oint \mathbf{J} \cdot d\mathbf{s} \text{ and } Q = \iiint \rho \, dv$$

$$\text{Then, } \oint \mathbf{J} \cdot d\mathbf{s} = -\frac{d}{dt} \iiint \rho \, dv$$

Using Divergence theorem

$$\iiint \nabla \cdot \mathbf{J} \, dv = -\frac{d}{dt} \iiint \rho \, dv$$

Two scalar quantity $\nabla \cdot \mathbf{J}$ and $-\frac{d\rho}{dt}$ are integrated over some volume and the value of these quantities is same.

∴ There two quantity must be equal.

$$\nabla \cdot \mathbf{J} = \frac{-d\rho}{dt}$$

$$\text{or } \nabla \cdot \mathbf{J} + \frac{d\rho}{dt} = 0$$

The above equation is known as continuity equation. This has a wide significance in **law of conservation of charge**.

$$35. \text{ Given, } N = 100 \text{ turns, } i = 0.1 \text{ A}$$

$$r = 10 \text{ cm} = 10 \times 10^{-2}$$

$$\text{Then } A = \pi r^2 = \pi \times 100 \times 10^{-4} \text{ and}$$

$$\text{Magnetic dipole moment} = NiA = Ni \pi r^2$$

$$= 100 \times 0.1 \times \pi \times 100 \times 10^{-4} = 0.1 \pi \text{ A-m}^2.$$

$$37. VSWR = \frac{|V_1|}{|V_R|} = \frac{R_L}{R_0}$$

$$38. \nabla \cdot \mathbf{D} = \rho$$

$$\mathbf{D} = e\mathbf{E}$$

$$\nabla \cdot \mathbf{E} = [\rho/e]$$

$$39. Q = 100 \text{ C and } r = 100 \text{ m}$$

$$E = \left(\frac{Q}{4\pi\epsilon r^2} \right) \text{ and } D = \epsilon E.$$

$$40. V = [Q/4\pi\epsilon R]; C = [Q/V]$$

$$C = 4\pi \epsilon_0 R$$

$$= 4\pi \epsilon_0 \times [1/4\pi \epsilon_0] = 1 \text{ F.}$$

$$42. K_1 = \frac{Z_L - Z_o}{Z_L + Z_o} = \frac{75 - Z_{o1}}{75 + Z_{o1}} \\ = \frac{75 - 225}{75 + 225} = \frac{150}{300} = \frac{-1}{2}$$

$$K_2 = \frac{Z_L - Z_o}{Z_L + Z_o} = \frac{75 - Z_{o2}}{75 + Z_{o2}} \\ = \frac{75 - 25}{75 + 25} = \frac{50}{100} = \frac{1}{2}$$

$$S = \frac{1 + |K|}{1 - |K|}$$

$$|K_1| = |K_2|.$$

$$43. Z_o = \sqrt{Z_{sc} \cdot Z_{oc}} \\ Z_o = \sqrt{100 \times 64} = 80.$$

$$44. Z_o = \sqrt{Z_{in} \cdot Z_L}$$

$$Z_{in} = \frac{Z_o^2}{Z_L} = \left[\frac{(50)^2}{100} \right] = \left[\frac{2500}{100} \right] = 25 \Omega.$$

$$45. K = \frac{Z_L - Z_o}{Z_L + Z_o} = \frac{-jZ_o - Z_o}{-jZ_o - Z_o} \\ = \frac{-Z_o(1+j)}{Z_o(1-j)} = \frac{-1}{1} = -1$$

$$S = \frac{1+K}{1-K} = \frac{1+1}{1-1} = \frac{2}{0} = \infty.$$

$$47. E = \left[\frac{\rho_z}{2\epsilon_0} \right] = \frac{2 \times 10^{-9}}{2 \times 8.854 \times 10^{-12}} \\ = -36 \pi a_z \text{ v/m.}$$

$$48. \text{ Skin depth, } \delta = \sqrt{\frac{2}{\omega \mu \sigma}}$$

$$\frac{\delta_1}{\delta_2} = \frac{\sqrt{2/\omega_1 \mu \sigma}}{\sqrt{2/\omega_2 \mu \sigma}} = \sqrt{\omega_2/\omega_1} = \sqrt{f_2/f_1}$$

$$\text{or } \delta_2 = \delta_1 \sqrt{\frac{f_2}{f_1}} = 66 \sqrt{\frac{1}{2}} = 46.66 \\ = 47 \mu\text{m.}$$

$$49. C = 4\pi\epsilon_0 R$$

$$R = \frac{1}{4\pi\epsilon_0}$$

$$50. \vec{T} = \vec{m} \times \vec{B} = I \vec{A} \times \vec{B} = I \pi r^2 a_z \times \vec{B}.$$

CHAPTER 6

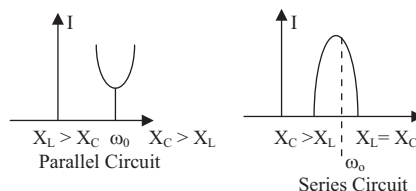
LEVEL 1

1. Faraday's law: Whenever the magnetic flux linked with an electric circuit is changed, an emf is induced in the circuit. By disconnecting the instrument, the flux gets charged and hence the spark results.

2. Only shering bridge can be used for measurement of dielectric loss of a capacitor.

Other is DE-Sauty's Bridge. Which can measure Dielectric loss.

3.



4. Capacitor store energy in the form of electric field and inductor store energy in the form of magnetic field. $E_E = [1/2] V^2$,

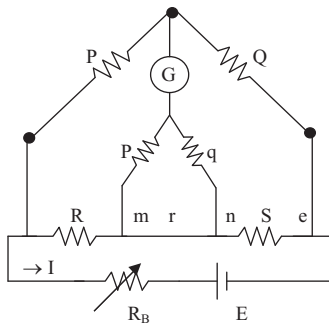
$E_M = [1/2] L I^2$, Due to current magnetic field exist i.e., Ampere law.

5. Shering bridge is widely used for the measurement of capacitance and dissipation factor.
6. Storage oscilloscope are capable of retaining the image on screen for longer time than that possible with conventional high persistence phosphors. Example of these are capture storage of transient and steady display of very low frequency signals.
7. The bombardment of electron on screen given rise of secondary emission of electron. The secondary electrons are collected by an aqueous solution of graphite called aquadag coating. Collecting of secondary electron is necessary to keep screen in a state of electrical equilibrium.
8. Precision of instrument is a measure of the reproducibility of measurements i.e., gives a fixed value of quantity, precision is a measure of the degree of agreement with a group of measurement. Precision is used in measurement to describe the consistency or reproducibility of results.
9. Each component in a A.C. bridge has defining screen connected to one end, very high accuracy in measurement is made possible by additional Wagner earthy device, it removes all the earth capacitance from bridge network.
13. Factor which complicates the behaviour of the A.C. bridge are the stray coupling between one bridge arm and another arm from element to ground factor usually error are:
 - (a) Stray conductance effect due to imperfect insulation.
 - (b) Mutual inductance effect, due to magnetic coupling between conductor at different potential.
 - (c) Stray capacitance effect due to electrostatic field between conductor at different potential.
 - (d) Residue component.
14. DC Sauty's bridge is the simplest method of comparing two capacitors, capacitance is measured by only varying the value of resistance.
15. In energy meter a slow but continuous rotation is obtained even when there is no current flowing through the current coil and only pressure coil is energized, this is called creeping. Major cause of creeping is over combination for friction and excessive voltage across the potential coils.
17. Impedance of an inductance is directly proportional to the frequency. Hence, harmonic frequency components are more attenuated as compared to the fundamental frequency.

18. $C = [\epsilon_0 \epsilon_r A/d]$. On inserting a dielectric material ($\epsilon_r > 1$), C increases.
20. A thermistor is generally fabricated a semiconductor material having a large nonlinear temperature coefficient of resistance.

Thermistor are compared of sintered mixture of metallic oxides such as manganese, nickels cobalt copper, iron and uranium.

21. In a permanent magnet moving coil (PMMC) meter, the current to be measured is passed through a movable coil placed in the magnetic field of a permanent magnet. The interaction between steady magnetic and the magnetic field due to current in the coil causes angular movement of the coil. Resulting angular deflection is directly proportional to the dc current through the coil. A sinusoidal current will simply cause vibration of the coil about its undeflected position.
22. Kelvin diode bridge is used to measure the low resistance. The Kelvin double bridge in corporate idea of second set of ratios—hence name double bridge the use of four terminal resistor for low resistance arms. Shown in figure, first of ratio arm P and Q . The second set of ratio arms p and q is used to connect the galvanometer to point d at appropriate potential between point in m and n eliminate the effect of connecting load of resistance r between known resistance R and standard resistance S .



23. In Dual trace oscilloscope in alternate mode provide the sweep speed is much greater than the of CRT phosphor. The alternate mode can not be used for displaying low frequency signals it used for high frequency signals.
24. Wagner earth connection is a method of connection used in c bridge circuit which minimizes the admittance between detector terminals and the ground.
26. Electrostatic instrument draw negligible power from mains initial current drawn by instrument which connected cross the D.C. mains is charging current which is dies down gradually depending upon the insulation resistance of meter which is

order of $10^{12} \Omega$. The final current with D.C. operation to zero on A.C. operation current draw depends upon the impedance of meter circuit. The current draws on A.C. fairly small.

27. Deflection of thermo couple instrument
 $\theta = K_3 I^2$
 $K_3 = a/c_1 K_2 R \rightarrow \text{constant}$
 Thermocouple indicate RMS value of current.
30. Thermistor: A resistor, usually fabricated from semiconductor material, that a large nonlinear negative temperature coefficient of resistance. An electrolyte, such as a viscous solution of water glass, is sometime used as the temperature-sensitive element. The thermistor is usually shaped as a rod, bead or disc and named accordingly. Applications include compensation for temperature variations in other components, used as a nonlinear circuit element, and for temperature and power measurements.
33. Advantages of electronic meter
- High input impedance and low power consumption due to power supplied from auxiliary source.
 - Detection of low level signal of the order of less than $50 \mu A$ and less than 5 mV due to amplifying properties.
 - High frequency range (10–100 MHz) some electronic voltmeter have range from dc to hundred of MHz. It is suitable for RF measurement.

35. $W_1 \propto \cos(30 + \phi)$

$W_2 \propto \cos(\phi - 30)$

37. The natural frequency of vibration of a reed used in a vibrating reed frequency meter, can be increased by decreasing the length of the reed.
39. Galvanometer Recorders

In these recorders, a pen assembly mouthed on the end of the pointer of a rugged D'Arsonval movement is used. While measuring a quantity by such recorders, the restraining springs of the movements provide a counterforce which balances the force produced by the quantity under measurement. Such recorders usually employ strip charts.

A basic diagram of such a recorder D'Arsonval galvanometer is some what different form the ordinary D'Arsonval galvanometer. As the friction torque in a recorder is high due to larger weight of the moving system and friction between the pen and the chart, so that large deflecting torque is required. Obviously, the controlling torque required will be also large. So, in such recorders large moving coil and strong magnetic field

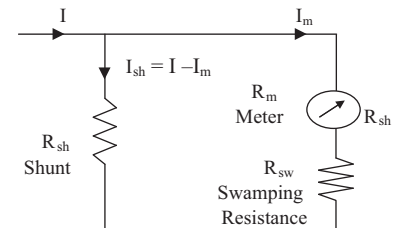
are employed. Galvanometer used in a recorder is also made critical damped to avoid overshoot but this result in the slow response time.

40. Advantages of electronic meter

- High input impedance and low power consumption due to power supplied from auxiliary source.
- Detection of low level signal of the order of less than $50 \mu A$ and less than 5 mV due to amplifying properties.
- High frequency range (10–100 MHz) some electronic voltmeter have range from DC to hundred of MHz. It is suitable for RF measurement.

42. The temperature error can be eliminated when the shunt and the moving-coil are made of the same material.

Use of *swamping resistance of manganin* having resistance 20 to 30 times the coil resistance is connected in series with the coil and a shunt.



43. Ammeter shunt are of very low value, for low value resistance measurement Kelvin double bridge is best suitable.
46. In a **flux meter**, the controlling torque is not provided at all.
47. Dummy **strain, gauge** is used in conjunction with the main strain gauge to compensate temperature effects.
48. **Half effect device** can be used to multiply two signals.
51. The bandwidth requirement of an FM telemetry channel is about ten times that of an AM telemetry channel.
52. The recording head in a magnetic tape responds to electrical signal and creates a magnetic signal.
53. Bifilar winding techniques is adopted to reduce the self-inductance of a wire-wound standard resistor.

56. Meter current, $I_m = I_f \frac{R_x}{R_x + R_p}$

Where R_x = unknown, and

$R_p = \frac{R_1 R_m}{R_1 + R_m}$, which is quite low

Where, R_x is in high value range, variation in the value of R_x causes hardly any variation in I_m and thus the scale is highly cramped for high resistance values

60. When a high voltage is impressed across current coil, which is of very low resistance, the coil current will immediately burn out unless some protective device operates.

61. The frequency and hence energy of each of the photons will remain the same.

Since, $I \propto \frac{1}{r^2}$ the number of photons incident on the photocathode will be one fourth of the their initial number. The number of photoelectrons emitted will be accordingly on fourth in number as compared to this first case.

62. The bombarding electrons, striking the screen, releases secondary emission electrons. The secondary electrons are collected by an aqueous solution of graphite called aquatic which is connected to the Second electrode. Collection of electrons is necessary to keep the screen in a state of electrical equilibrium.

63. Resistive Hygrometers

Dunmore element and the pope cell are the two extensively used percent relative humidity (% RH) electrical transducers.

The Dunmore sensor makes use of bifilar-wound insert wire grid on an isolative substrate coated with a lithium chloride (LiCl) solution of a controlled concentration. The hygroscopic nature of this salt makes it to take up water vapour from the surrounding atmosphere.

With the increasing in relative humidity, the salt (lithium chloride) film absorbs more and more water vapour from the air and so its **resistance decreases** markedly. Thus, the AC resistance of the transducer is an indication of the prevailing % RH. Bridge type resistance measuring circuitry with an AC excitation is used normally as DC excitation polarizes the transducer, eventually causing loss of calibration. The resistance-relative humidity relation is quite non-linear.

64. Measuring instrument have high input impedance a CRO too have higher impedance of order of $1\text{M}\Omega$

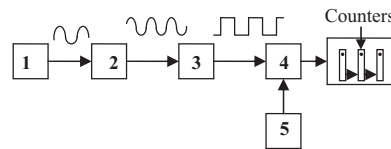
65. The storage type CRO is rapidly becoming one of the most useful tools in the presentation of very slowly swept signal and finds many application in the mechanical and biomedical fields. In the conventional CRT the persistence of the phosphor ranges from microsecond to perhaps seconds. In application where, the persistence of the screen is smaller than the rate at which the signal sweeps across the screen, the start of the display will have disappeared before the end of the display is written.

66. **Multiple Beam Oscilloscopes:** In many cases it becomes necessary to compare one signal with another. In such cases

Multiple Beam Oscilloscopes are used. Multiple Beam Oscilloscopes enclose in the signal tube several beam producing system each with is vertical pair or plates, but mostly with a common time-base. Each Y-channel has its own amplifier. The synchronization or triggering is done form the input of a desired Y-channel or form an external input voltage.

Double beam Oscilloscopes use two electron guns with in the same cathode ray tube. The electron beams of the two channel of the two channel are completely independent of each other. The same effect may be produced by a single electron gun, the output it being split into two independently controllable electron beams.

69. Digital frequency meter



Where,

1. Unknown frequency source
2. Amplifier
3. Schmitt trigger
4. Start stop gate
5. Gating signal (From crystal)

Figure: Basic circuit of a digital frequency meter.

There are two signal to gate i.e., square type signal from schemitt trigger derived from unknown frequency source which is used as gate width opening signal and other derived form crystal oscillator. Both are important for accuracy of frequency converter.

70. LCD displays are preferred over LED displays because they consume less power.

72. The construction of a signal phase electrodynamicometer type power factor meter. It consist of a fixed coil which acts as the current coil. This coil is split up into two parts and carries the current the circuit under test. Therefore, the magnetic field produced by this coil is proportional to the main current. Two identical pressure coil A and B pivoted on a spindle with it, and coil B has a highly inductive choke coil L connected in series with it. The two coils carry the same value of current at normal frequency i.e., $R = \omega L$. The current through coil A is in phase with the circuit voltage, while that through coil B lags the voltage by an angle Δ which is nearly equal to 90° . The angle between the planes of coils is coil made equal to Δ . There is no controlling device. Connection to moving coil are made by thin silver or gold ligaments

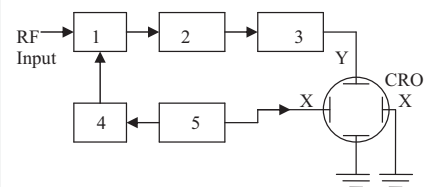
which are extremely flexible and thus give a minimum control effect on the moving system.

76. The spectrum analyzer are sophisticated instruments which are capable of portraying graphically the amplitude as a function of frequency in a portion or RF spectrum. These instruments find applications for measurement of attenuation, FM deviation, and frequency in pulse studies.

The basic spectrum analyzer is designed to represent graphically, a plot of amplitude versus frequency of as selected portion of the frequency spectrum under study. The modern spectrum analyzer basically consists of a narrow band super heterodyne receiver and a CRO The receiver is electronically tuned by varying the frequency of the local oscillator. A simplified block diagram of a swept frequency spectrum analyzer is shown in figure.

The circuit incorporates a sawtooth generator which supplies a ramp voltage to the frequency control element of the voltage tuned local oscillator. The local oscillator then sweeps through its frequency band at a recurring liner rate. The same voltage is simultaneously applied to the horizontal plates of the CRO. The RF signal to be tested is applied to the input of the mixer state.

The sawtooth generator makes the local oscillator sweep through its frequency band to beat with the input signal to produce the desired intermediate frequency (IF). An IF component is produced only when the corresponding component is present in the RF input signal. The resulting IF signals are amplified, and then detected. After that, they are applied to the vertical deflection of the CRO, thereby producing a display of amplitude versus frequency on the screen.



Where,

1. Mixer
2. If amplifier
3. Detector and Video amplifier
4. Voltage tuned local oscillator
5. Sawtooth generator

Figure: Basic swept receiver spectrum analyzer.

77. Bigger size Mirror results in increased inertia constant J .

$$f_n = \frac{1}{2\pi} \sqrt{\frac{K}{J}} \text{ and}$$

$$A = \frac{GI_m}{\sqrt{(D\omega)^2 + (K - J\omega^2)^2}}$$

as J increases both f_n & A decrease.

78. Analog storage oscilloscope (variable persistence storage type).
79. Actual loading arrangements would involve a considerable waste of power. In order to avoid this 'Phantom' or 'Fictitious' loading is done.
99. It is used in A.C. bridge circuits for eliminating the stray capacitance (electrostatic field) exist between various bridge element and ground.
100. Hall effect pick up can measure the magnetic flux.

LEVEL 2

1. Rectifier type instrument calibrated to rms Value

$$\text{Hence, reading} = 10 \times 1.11 = 11.1 \text{ V}$$

2. $\theta_x \propto I^2$

$$\frac{\theta_2}{\theta_1} = \frac{I_2^2}{I_1^2} \Rightarrow I_2 = I_1 \sqrt{\frac{\theta_2}{\theta_1}}$$

$$= 1 \sqrt{\frac{1}{2}} = 0.707 \text{ A}$$

3. Moving iron reads I_{rms}

$$I_{rms} \text{ for half wave rectifier is, } I_{rms} = \frac{I_m}{\pi}$$

$$\Rightarrow I_m = 2 \times I_{rms} = 2 \times 5 = 10$$

Moving coil reads I_{av}

$$I_{av} = \frac{I_m}{\pi} = \frac{10}{\pi} = 3.18$$

4. Coil series aiding

$$L_{eq} = L_1 + L_2 + 2M$$

$$2M = L_{eq} - L_1 - L_2$$

$$= 40 - 10 - 15 = 15$$

Coil Series opposing

$$L_{eq} = L_1 + L_2 - 2M$$

$$= 10 + 15 - 15$$

$$= 10 \text{ mH}$$

5. Time period $= \frac{1}{f} = \frac{1}{400 \times 10^3} = 2.5 \mu\text{s}$

$$\text{No. of pulse} = \frac{\text{Total Time}}{\text{Time period}} = \frac{20 \text{ ms}}{2.5 \mu\text{s}}$$

$$= 8000$$

6. 4th stage output frequency $f = \frac{1 \times 10^6}{1 \times 10^4}$
- $$= 100 \text{ Hz}$$

$$\text{Hence Time period } T = \frac{1}{f}$$

$$\Rightarrow T = \frac{1}{100} = 10 \text{ ms}$$

7. % of quantization error

$$= \pm \frac{(1/2) \text{ LSB}}{2^n - 1} = \frac{0.5}{4095} = \pm 0.01221\%$$

8. One of the wattmeter reading $\alpha \cos(30^\circ + \phi)$

$$9. 2\% \text{ of } 300 \text{ V} = \frac{2}{100} \times 300 = 6 \text{ V}$$

$$\text{Then \% error} = \frac{6}{30} \times 100 = 20\%$$

$$\text{Hence range} = 30 \pm 20\% = 30 \pm 6$$

$$= 24 \text{ V to } 36 \text{ V}$$

10. $Rt_2 = R[1 + \alpha(t_2 - t_1)]$

$$Rt_{2\max} = 1.26[1 + 500 \times 10^{-6}(75 - 25)] \text{ k}\Omega$$

$$R_{\max} \text{ at } 75^\circ = 1.26(1 + 500 \times 10^{-6} \times 50) \text{ k}\Omega$$

$$= 1.2915 \text{ k}\Omega$$

11. Standard resistance

$$R_s = \frac{101.8}{10 \times 100} \times 10 = 101.8 \Omega$$

$$\text{Standard Current } I_s = \frac{1.018}{101.8} = 10 \text{ mA}$$

12. Without controlling torque pointer strike to beyond the scale for Half circle scale. For full circle scale rotate freely.

13. External resistance of low value are connected in parallel to meter to increases the range of meter. If no resistance are used then, it reads maximum value.

14. **Correction for Distributed Capacitance**

The distributed capacitance or self-capacitance of measuring circuit modifies the true value of Q . the measured value of Q is less than the true value by a factor that upon the value of the distributed (self) capacitance and the tuning capacitor. It can be shown that

$$\therefore Q_{\text{true}} = Q_{\text{meas}} \left(1 + \frac{C_d}{C} \right)$$

C_d = distributed or self-capacitance and C = tuning capacitance

15. $Q \cdot F = Q_L = \frac{V_L}{V_R} = \frac{V_C}{V_R} = \frac{10 \text{ V}}{500 \text{ mV}} = 20$

16. Always used high sensitivity (high input impedance) meter to avoid the loading effect.

17. Energy consumed

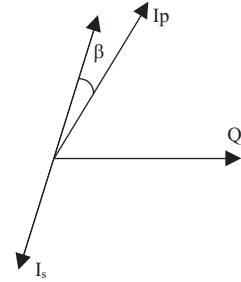
$$= \frac{230 \times 20 \times 1 \times 2}{1000} \text{ kWh} = 9.2 \text{ kWh}$$

$$\text{Revolution} = 1380$$

$$\text{Meter constant} = \frac{\text{Revolution}}{\text{Energy consumed}}$$

$$= \frac{1380}{9.2} = 150 \text{ revs/kWh}$$

18. In a digital voltmeter, 'over-ranging' impels that an over-range indicator starts glowing.



$$\text{Phase error } \beta = 3^\circ$$

$\therefore$ angle between the primary and secondary currents

$$= 180^\circ - \beta = 180^\circ - 3^\circ = 177^\circ$$

20. Energy consumed as indicated by energy meter = Revolution/meter constant

$$= \frac{90}{1800} 10^{-3} = 0.05 \text{ kWh}$$

Actual energy consumed

$$= 230 \times \left(\frac{10}{2} \right) \times 1 \times \frac{3}{60} \times 10^{-3} \text{ kWh}$$

$$= 0.0575 \text{ kWh}$$

$$\text{Error} = 0.0500 - 0.0575 = -0.0075 \text{ kWh}$$

$$\therefore \text{Meter is slow by } \frac{0.0075}{0.0500} \times 100 = 15\%$$

21. Gauge factor $G_f = \frac{\Delta R/R}{\text{Strain}}$

$$= \frac{(110.52 - 110)/110}{\text{strain}}$$

$$\therefore \text{Strain} = \frac{\Delta R/R}{G_f} = \frac{0.52}{110.00} \times \frac{1}{2.03}$$

$$= 2.33 \times 10^{-3} \Rightarrow 2.06 \times 10^{-3}$$

23. $P = I^2 R$

$$\frac{dP}{P} = 2 \frac{dI}{I} + \frac{dR}{R}$$

$$= \pm 2 \times 0.5 \pm 0.2$$

$$= \pm (1 + 0.2) = \pm 1.2\%$$

24. Moving iron type meter measures rms value

$$\text{Reading} = \sqrt{10^2 + \left(\frac{10}{\sqrt{2}} \right)^2}$$

$$= \sqrt{100 + \frac{100}{2}} = \sqrt{100 + 50} = \sqrt{150}$$

$$25. C_d = \frac{C_1 - n_2 C_2}{n^2 - 1}$$

$$\text{Here } n = \frac{4}{2} = 2$$

$$C_1 = 4500 \text{ pF}$$

$$C_2 = 90 \text{ pF}$$

$$C_d = \frac{C_1 - 4 C_2}{2^2 - 1} = \frac{450 - 4 \times 90}{3} \\ = \frac{450 - 360}{3} = \frac{90}{3} = 30 \text{ pF}$$

29. The error specified is always with respect to full scale reading and this is the maximum error that may be present at any deflection.

Therefore, Percentage error

$$= \frac{1.0}{100} \times 150 \times \frac{1}{75} \times 100 = 20\%$$

30. Form factor = $\frac{\text{Rms value of the wave}}{\text{Mean value of the wave}}$

Moving iron instrument will shown RMS value.

Rectifier voltmeter is calibrated to read RMS of sinusoidal voltage, i.e., with form factor of 1.11.

Therefore, Mean value of the applied voltage = $\left(\frac{V_2}{1.11} \right)$

$$\text{Hence, Form factor} = \frac{V_1}{V_2 / 1.11} = \frac{1.11 V}{V_2}$$

31. Given $r_{cc} = 0.01 \Omega$ and $r_{vc} = 1000 \Omega$

There are two ways in which the current coil and voltage can be connected. The wattmeter reads high by an amount equal to power loss in current coil in one case and in voltage coil in the other.

The two possible power losses are

$$(1) I_c^2 \cdot r_{cc} = 20^2 \times 0.01 = 4W$$

$$(2) \frac{V^2}{r_{vc}} = \frac{30^2}{1000} = 0.9W$$

Percentage errors are

$$(1) \frac{4}{100} \times 100 = 0.66$$

$$(2) \frac{0.9}{600} \times 100 = 0.15$$

32. For the phase sequence and connections specified, the reading in the wattmeter of line A $\propto (30 + \theta)$,

Where, θ = lagging load power factor angle

Since, it reads zero, $\theta = 60^\circ$

Or load p.f. = $\cos 60^\circ = 0.5$ lagging.

$$33. f = \frac{2}{2\pi\sqrt{10^{-6}}} = \frac{1000}{\pi}$$

34. 400 revolutions $\rightarrow$ kWh

When the power is 1 kW, the speed

$$= \frac{400}{60} = \frac{20}{3} \text{ rpm}$$

$$\text{When the power} = \frac{240 \times 10 \times 0.8}{1000} = 19.2$$

$$\text{Then, } = \frac{20}{3} \times 1.92 = 12.8 \text{ rpm}$$

37. Thermocouple reads rms value $\theta \propto I^2$

$$\text{From } \frac{\theta_1}{\theta_2} = \frac{I_1^2}{I_2^2}; \quad \frac{1}{5} = \frac{10^2}{I_2^2}$$

$$I_2^2 = \frac{100}{5} = 20$$

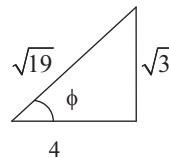
$$\Rightarrow I_2 = 4.47 \text{ A}$$

38. Dual trace oscilloscope user a single electron gun and produces multiple traces by switching the y-deflection plates from one input signal to another. It (this means the y-channel is shared by may signal.

$$39. \frac{f_v}{f_H} = \frac{T_H}{T_v}$$

$$\therefore f_v = \frac{5}{2} \times 1000 = 2500 \text{ Hz.}$$

- 40.



$$\tan \phi = \sqrt{3} \frac{W_1 \times W_2}{W_1 + W_2} = \sqrt{3} \frac{5-3}{5+3} = \frac{\sqrt{3}}{4}$$

$$\therefore \cos \phi = \frac{4}{\sqrt{19}} = 0.917$$

(lagging due to inductive load)

41. Number of flip flop for a counter is $n \geq \log_2 N$

42. Temperature coefficient

$$\alpha_t = \frac{\Delta R/R}{\Delta T} \Rightarrow \Delta T = \frac{\Delta R/R}{\alpha_t}$$

$$= \frac{10/5000}{0.04} = 0.0560^\circ \text{C}$$

A change of 1°C in temperature is reflected as a change of $5000 \times 0.04 = 200$ ohms of resistance in thermistor resistance.

A resistance changes of 10 ohm is equivalent to $\frac{10}{200}^\circ \text{C} = 0.05^\circ \text{C}$

43. Time period of clock frequency

$$T = \frac{1}{400 \times 10^{-3}} = 0.0025 \text{ ms}$$

$$\text{Number of pulse} = \frac{\text{Total time}}{\text{Time period}} \\ = \frac{20}{0.0025} \\ = 8000$$

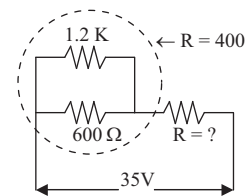
44. In two wattmeter method of power measurement in balanced, three phase Network, the reading. R_1 and R_2 are proportional to

$$\cos(\theta - 30) \text{ and } \cos(\theta + 30),$$

where θ is the power factor angle of the load, therefore, it $\theta = 60^\circ$, i.e., if load power factor is 0.5 one of the wattmeter shall read zero.

power.

- 45.



Since the continuation of voltmeter

Resistance 1.2 K and $600 = 1200 \parallel 600$

$$= \frac{1200 \times 600}{1200 + 600}$$

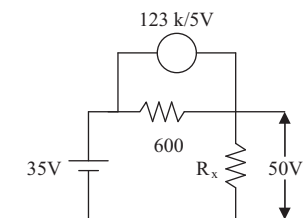
$$= 400 \Omega$$

Voltage across unknown resistance $R = 35 - 5 = 30 \text{ V}$

Then Unknown resistance value

$$R = 30 \times \left[\frac{400}{5} \right] \\ = 2.4 \text{ k}\Omega$$

Second Method



Parallel combination of series resistance and meter resistance

$$= \frac{600 \times 1200}{600 + 1200} = 400 \Omega$$

Voltage across the unknown resistance is 30 V.

By voltage division rule

$$V_x = \frac{R_x}{R_x + R_s} \times V_s$$

$$30 = \frac{R_x}{R_x + 400} \times 35$$

$$\begin{aligned} 30 [R_x + 400] &= R_x \times 35 \\ 30 \times R_x + 12000 &= R_x \times 35 \\ 5R_x &= 12000 \\ R_x &= 2.4 \text{ k}\Omega \end{aligned}$$

$$\begin{aligned} 46. \text{ Resolution} &= \frac{1}{\text{Number of steps}} \times \text{FSV} \\ &= \frac{\text{FSV}}{\text{Number of steps}} \\ &= \frac{1}{9999} \times 9.999 \text{ V} = 10^{-3} = 1 \text{ mV} \end{aligned}$$

$$\begin{aligned} 47. RC &= ML^2 T^{-3} I^{-2} \times M^{-1} L^{-2} T^4 I^2 = T \\ \frac{L}{R} &= \frac{ML^2 T^{-2} I^2}{ML^2 T^{-3} I^{-2}} = T I^4 = T \\ LC &= ML^2 T^{-2} I^2 \times M^{-1} L^{-2} T^4 I^2 = T^2 I^4 \end{aligned}$$

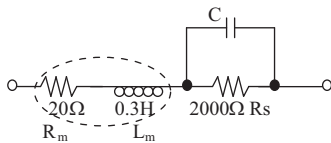
$$\begin{aligned} 48. \mu_o &\rightarrow \text{Permeability of medium} \\ &= 4\pi \times 10^{-7} = 1.257 \times 10^{-6} \\ \epsilon_o &\rightarrow \text{Electric Permittivity of medium F/m} \\ \epsilon &= [1/36\pi] \times 10^9 = 8.85 \times 10^{-12} \\ \text{Velocity of light } C &= \frac{1}{\sqrt{\mu_o \epsilon_o}} \\ &= \frac{1}{\sqrt{1.257 \times 8.884 \times 10^{-6} \times 10^{-12}}} \\ &= 3 \times 10^8 \text{ m/s} \text{----- unit LT}^{-1}. \end{aligned}$$

$$\begin{aligned} 49. \text{ Maximum voltage } V_{\max} &= 110 \text{ V} \\ \text{Maximum Current } I_{\max} &= 5 \text{ A} \\ \text{Impedance } (Z) &= \frac{110}{5} = 22 \Omega \end{aligned}$$

$$\begin{aligned} 50. \text{ Potential difference} &= [\text{Energy/Charge}] \\ V &= \frac{E}{q} = \frac{50}{10} = 5 \text{ V} \end{aligned}$$

$$\begin{aligned} 51. n &= \frac{4}{2} = 2 \\ C_d &= \frac{C_1 \times f_1 - C_2 \times n^2}{n^2 - 1} \\ &= \frac{460 \times 1 - 4 \times 100}{3} = 20 \text{ pF} \end{aligned}$$

52.



$$\begin{aligned} R_T &= R_s + R_m \\ &= 2000 + 200 = 2200 \end{aligned}$$

$$\begin{aligned} \text{The value of Capacitance } C &\equiv \left(\frac{L}{R^2} \right) \\ &= \left(\frac{0.3}{2200^2} \right) \\ &= 0.062 \text{ }\mu\text{F}. \end{aligned}$$

$$\begin{aligned} 53. \text{ Speed in rpm} &= \frac{\text{Counts per minute}}{\text{Number to teeth}} \\ &= \frac{3600}{60} = 60 \end{aligned}$$

$$\begin{aligned} 54. \text{ Maximum possible error at any reading} &= \frac{150}{100} \times 1.5 \text{ V} \\ \therefore \text{ Percentage error at a reading of } 8.3 \text{ V} &= \frac{1.5}{8.3} \times 100 \\ &= 18.1\% \end{aligned}$$

$$\begin{aligned} 55. \text{ Shunt resistance, } S &= \left(\frac{R_m}{m-1} \right) \Omega \\ \text{where, } R_m &= \text{movement resistance } 100 \text{ ohm} \\ m &= \text{multiplying factor} \\ &= \left(\frac{I}{i} \right) = \frac{100 \times 10^{-3}}{1000 \times 10^{-6}} = \frac{1}{10} \times 1000 = 100 \\ I &= \text{total current} \\ I &= \text{current through the movement} \\ \text{Hence, } S &= \frac{100}{100-1} \approx 1 \text{ ohm} \end{aligned}$$

$$\begin{aligned} 56. \text{ Current in shunt} &= \frac{\text{Potential difference across the shunt coil}}{\text{Shunt resistance}} \\ &= \frac{500 \times 10^{-3}}{20 \times 10^{-3}} = 25 \text{ A} \end{aligned}$$

$$\begin{aligned} 57. \text{ Sensitivity} &= \frac{1}{\text{Current range of meter}} \\ &= \frac{1}{(25+25) \mu\text{A}} = 200 \text{ k}\Omega/\text{volt} \end{aligned}$$

58. Since, it is a peak responding meter, for $(1/\sqrt{2})$ volt peak value it indicates 1 V and 1 V DC input, peak values is 1 V itself or would be taken as zero for negative polarity.

Consequently reading would be

$$\frac{1}{\sqrt{2}} \times 1 \text{ or } 1 \times \frac{1}{\sqrt{2}} \times 0 \text{ i.e., } 0.707 \text{ V or } 0 \text{ V}$$

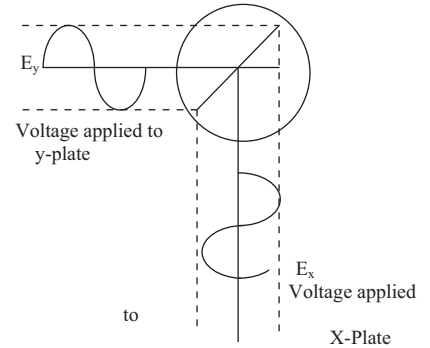
59. When on X and Y plate signal of same frequency it represent straight line. For such a trace, both the signals are identical.

Since x-plate signal is $2 \sin \omega t$, the same is the y-plate signal.

Second Method

When two sinusoidal signal of equal frequency which are in phase with each other are applied to the horizontal and

vertical deflection plate, pattern appears on screen is straight line. So applied to X-plate is $2 \sin \omega t$ then the voltage applied y-plate also $2 \sin \omega t$



$$60. \text{ Time constant } CR = P = 10 \text{ M}\Omega \times 2 \Rightarrow F.$$

$$61. \text{ Nyquist sampling i.e., } f_s \geq 2 f_{\max}.$$

$$\begin{aligned} 62. \text{ Burden} &= V \times I = 15 \text{ VA and } I = 5 \\ \text{Therefore } V &= 3 \text{ volt and the impedance} \\ &= [3/5] \\ &= 0.6 \text{ ohm} \end{aligned}$$

$$\begin{aligned} 63. \omega_n &= \left(\frac{2\Delta t}{D^2} \right) \sqrt{\frac{E}{3P(1-v^2)}} \text{ rad/s} \\ \omega_n &= 30 \text{ kHz} \\ \text{New } \omega_n &= \frac{2\Delta t/2}{D^2/4} = \frac{4\Delta t}{D^2} \\ &= 2 \times 30 \text{ kHz} = 60 \text{ kHz} \end{aligned}$$

64. The resistance of these voltmeter are

$$R_1 = \frac{100 \text{ volt}}{2 \times 10^{-3} \text{ amp}} = 50 \times 10^3 \Omega$$

$$R_2 = 100 \times 100 \Omega = 10^4 \Omega$$

$$R_3 = \frac{100 \text{ volt}}{1 \times 10^{-3} \text{ amp}} = 100 \times 10^3 \Omega$$

$$R_4 = \frac{10,000}{10 \times 10^{-3}} = 100 \times 10^3 \Omega$$

R_4 is largest of all. Hence, (d) is the correct choice.

$$\begin{aligned} 65. L &= 1 \text{ m}; B = 1 \text{ Wb/m}^2, v = 50 \text{ cm/sec.} \\ &= 50 \times 10^{-2} \text{ m/sec} \end{aligned}$$

$$\text{Hence, } e = LB v \sin \theta = 1 \times 1 \times 50 \times 10^{-2} \times 2 \sin 90^\circ = 0.5 \text{ V}$$

$$66. m = \frac{I}{I_m} = \frac{1 \text{ A}}{1 \text{ mA}} = 1000$$

$$R_s (m-1) = R_m \times I$$

$$R_s = \frac{R_m \times I}{m-1} = \frac{100 \times 1}{999}$$

$$R_s \times 999 = 1 \times 100$$

$$\text{Hence } R_s = \frac{100}{999} = 0.1001 \text{ ohm}$$

67. Limiting error

$$= \frac{\text{Accuracy} \times \text{Range}}{\text{Measured value}}$$

$$\text{Error} = \frac{0.75 \times 200}{100} = 1.5\%$$

Second Method

Relative limiting error is ratio of the error to nominal (Speed field) magnitude of quantity

$$\% \varepsilon_r = \frac{\delta A}{A_s} = \frac{(75/100) \times 200}{100} = 1.5\%$$

68. Form factor

$$= \frac{\text{RMS}}{\text{Average}} = \frac{0.707 I_m}{0.637 I_m} = 1.11$$

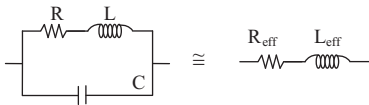
$$I_{av} = [2 I_m / \pi]$$

RMS value = 1.11 × average value

$$I_{rms} = [I_m / \sqrt{2}] = 1.11 \times 100 = 111 \text{ V}$$

69. The function of the reference electrode in a pH meter is to produce a constant potential regardless of the pH value of the solution under test.

71. Equivalent circuit of a coil (or inductor),



The arrangement becomes a resonating circuit with resonating frequency

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \text{ Hz.}$$

At this frequency the inductor behaves as a pure resistor. At higher frequencies the impedance becomes capacitive.

72. Hot wire anemometer is a device used to measure the liquid discharge.

73. Piezoelectric crystal voltage sensitivity (g) is defined as the ratio of electric field intensity to stress

$$\text{Therefore, } g = \frac{\text{electric field}}{\text{stress}}$$

74. Advantages of electronics Transducer

1. When dealing with electrical/electronic signals, the inertia effects are due to electrons which have negligible mass. Thus, the mass inertia effects are minimized
2. These systems can be controlled with a very small power level
3. The electrical output can be easily used, transmitted and processed for the purpose of measurement.

75. Gauge factor of a strain gauge is defined as the ratio of per unit change in resistance to per unit change in length of element i.e.,

$$GF = \frac{\nabla R/R}{\nabla L/L}$$

77. The most suitable primary standard for frequency is hydrogen master standard.

LEVEL 3

1. For a Wien Bridge oscillator, $f = [1/2\pi RC]$

$$(a) R = 1 \text{ k}\Omega, C = [1/2\pi] \mu\text{F}$$

$$f = \frac{1}{2\pi \times 1 \times 10^3 \times [1/2\pi] \times 10^{-6}} = 10^3 \text{ Hz}$$

$$(b) R = 3 \text{ k}\Omega, C = [1/18\pi] \mu\text{F}$$

$$f = \frac{1}{2\pi \times 1 \times 10^3 \times [1/18\pi] \times 10^{-6}} = 10^3 \text{ Hz}$$

The gain should be 3 for proper operation.

$$2. \frac{f_x}{f_y} = \frac{\text{points of tangency to vertical line}}{\text{points of tangency to horizontal line}} = \frac{1}{2}$$

3. As the element absorbs power, let it be R_x .

$$i = 1 = [6/(R_x + 1)]$$

$$R_x = 5 \Omega$$

$$P = [6/6]^2 \times 5 = 5 \text{ W.}$$

$$\text{For } 5 \text{ A, } P = 5^2 \times 5 = 125 \text{ W}$$

$$\text{For } 3 + \sqrt{(14)}, P = 227 \text{ W}$$

$$\text{For } 3 + \sqrt{(14)}, P = 2.75 \text{ W}$$

Hence, none of the above is correct

4. Deflection sensitivity of a CRT is defined as the deflection on the screen (in meters) per volt of deflection voltage

$$S = [D/E_d]$$

$$\text{Where } E_d = [V_d/d] \text{ V/m and}$$

$$D = \frac{LL_s}{V_A} \cdot \frac{V_d}{d}$$

$$\text{Deflection sensitivity, } S = [LL_s/V_A]$$

$$5. = 2RC \ln [(1 + \beta)/(1 - \beta)]$$

$$\text{Here, } \beta = [1/2] = [R/(r + R)]$$

$$= 2RC \ln 3 = 2T \ln 3$$

6. In two watt meter method

$$W_1 = \sqrt{3} V_p I_p \cos (30 + \theta)$$

$$W_2 = \sqrt{3} V_p I_p \cos (30 + \theta)$$

$$\theta = 60^\circ$$

$$\text{Hence, } W_1 = \sqrt{3} V_p I_p \cos 30 = 0$$

$$W_2 = \sqrt{3} [V_p^2/R] \cos (30 - 60)$$

$$= 1000 \text{ W}$$

7. Since the source is an A.C. voltage therefore

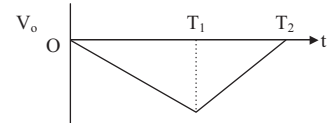
$$I_{3\text{rms}} = \sqrt{I_1^2 + I_2^2} = \sqrt{5^2 + 12^2} = \sqrt{169} = 13 \text{ A}$$

$$8. A_1 = \sqrt{A_2^2 + A_3^2} = \sqrt{3^2 + 4^2} = 5 \text{ A}$$

9. The meter will read during positive half wave rectifier.

$$V_{av} = \frac{V_m}{\pi R} = \frac{4}{\pi 10K} = \frac{0.4}{\pi} \text{ mA}$$

10.



The waveform for dual slope integrator is shown. The maximum frequency can be attained when $T_2 - T_1 = 0$ and, as

$$T_1 = 2^n T_C$$

where T_C = clock period and

n = number of bits.

$$\therefore f_{\max} = \frac{1}{2^n T_C} = \frac{f_c}{2^n} = \frac{10^6}{1024} \approx 1 \text{ kHz}$$

11. Output of full wave rectifier.

$$V_{dc} = \frac{2V_m}{\pi} = \frac{2\sqrt{2}}{\pi} V_{rms} = \frac{2\sqrt{2} \times 100}{\pi} = 90.03$$

For full deflection

$$R_m + R_s = \frac{90.03}{1 \times 10^{-3}}$$

$$R_s = 90.03 \times 10^3 - 0.1 \times 10^3 = 89.93 \text{ k}\Omega$$

Second Method

D.C. sensitivity is,

$$S_{dc} = \frac{1}{I_{fs}} = \frac{1}{1 \text{ mA}} = 10^3 \Omega/\text{V}$$

For full-wave rectifier A.C. sensitivity,

$$s_{ac} = 0.9 S_{dc} = 0.9 \times 10^3 = 900 \Omega/\text{V}$$

Resistance of multiplier,

$$R_s = S_{ac} V - R_m - 2 R_d$$

Since, diodes are ideal, $R_d = 0$

$$\text{The, } R_s = 900 \times 100 - 100 = 89.90 \text{ k}\Omega$$

13. Power indicated by wattmeter,

= Power consumed by load + Power loss in current coil

$$= 200 \times 20 + 20^2 \times 0.02 = 4008 \text{ W}$$

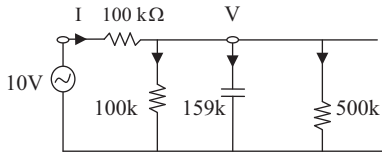
Load power = 4000 W

Then %increase

$$= \frac{4008 - 4000}{4000} \times 100 = 0.2\% \text{ more}$$

14. $f = 100$; $\omega = 2\pi f$; $C = 10 \text{ pF}$

$$\text{Here, } X_c = \frac{1}{\omega C} = 159 \text{ K}$$



Apply the KCL

$$\therefore \frac{10-V}{100} = V \left(\frac{1}{100} + \frac{1}{159} + \frac{1}{500} \right)$$

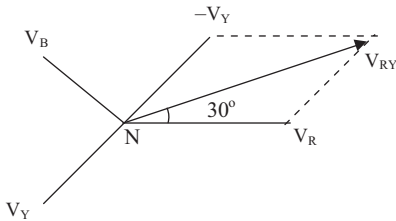
$$= 0.018V$$

$$\Rightarrow 10 - V = 1.82V$$

$$V = \frac{10}{2.82} = 3.53V$$

15. From the figure given in the question, we get

$$V_{RY} = 415 \angle 30^\circ; V_{BN} = \frac{415}{\sqrt{3}} \angle 120^\circ$$



Now, current through current coil is,

$$I_c = \frac{V_{RY}}{Z}$$

$$= \frac{415 \angle 30^\circ}{100 \angle 36.87^\circ} = 4.15 \angle -6.87^\circ$$

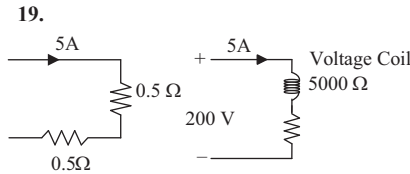
$$S = VI^* = 415/\sqrt{3} \times 4.15 \angle 126.87^\circ$$

$$= 994.34 \angle 126.57^\circ$$

Hence, $P = -597 \text{ W}$.

16. Power indicated by wattmeter,
= Power consumed by load + Power loss in current coil
= $200 \times 20 + 20^2 \times 0.02 = 4008 \text{ W}$
Total Load power = $200 \times 20 = 4000 \text{ W}$
Total power = 4008 W
Then %increase
= $\frac{4008 - 4000}{4000} \times 100 = 0.2\% \text{ more}$
17. The impedance of the inductor for n^{th} harmonic is n times the impedance for the fundamental frequency i.e., $X_L = \omega L$, so as impedance increase the current decreases but since the n^{th} harmonic voltage is n times the fundamental frequency signal, each harmonic signal gives the same current I_o .
 $\therefore$ Ammeter reading = $\sqrt{(I_o^2 + I_o^2 + I_o^2 + I_o^2)}$
= $\sqrt{4 I_o^2} = 2I_o$
18. Since, the voltage across the resistor of 1Ω is also to be 1 V , the current

flow through the resistor only (= 1 A).
The voltage source is carrier no current.
Hence the corresponding Power are $0, 1 \text{ Watt}, 1 \text{ Watt}$



Watt-meter current coil circuit resistance
= $(0.5 + 0.5) = 1 \Omega$

Watt meter voltage coil circuit resistance
= 5000Ω

The watt-meter is tested for full load, i.e., the current in current coil is 5 A & voltage a cross voltage coil is 200 V .

The associated power consumed are

$$I^2 R \text{ and } [V^2/R]$$

$$= 5^2 \times 1 \text{ and } [(200)^2/5000]$$

$$= 25 + 8 = 33 \text{ watt.}$$

20. When bridge is balance

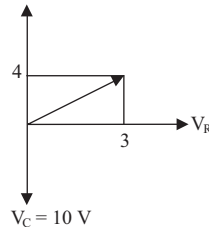
$$R + R = 2R$$

$$R + R = 2R$$

$$2R \parallel 2R = R$$

$$R \parallel R = 0.5R$$

21. $V_L = 14$

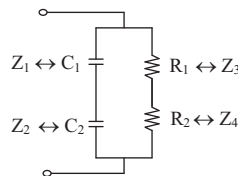


Net voltage across reactive element taken together

$$V_X = (V_L - V_C) = (14 - 10) = 4 \text{ V}$$

$$\text{Supply voltage} = \sqrt{(V_R^2 + V_X^2)} = \sqrt{(3^2 + 4^2)} = 5 \text{ V}$$

- 22.



For the voltage division to be independent of frequency, the impedance ratio is equal & independent of frequency i.e.,

$$\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}$$

Or $Z_1 Z_4 = Z_2 Z_3$

$$\frac{1}{j\omega C_1} R_4 = \frac{1}{j\omega C_2} R_3$$

$$\text{or } C_2 R_4 = C_1 R_3$$

Where, $C_1 = 1 \mu\text{F}$, $R_3 = 10 \text{ K}$, $R_4 = 1 \Omega$

$$C_2 = \frac{C_1 R_3}{R_4} = \frac{1 \mu\text{F} \times 10 \text{ K}}{1 \text{ K}} = 10 \mu\text{F}$$

23. $X_1 = (10 + 0.1) = 10.1 \Omega$

$$X_2 = \left(\frac{5000 \times 10}{5000 + 10} \right) = \frac{50000}{5010} = 9.98 \Omega$$

---Parallel with voltmeter

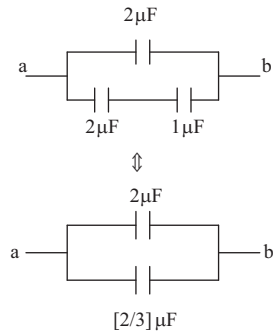
$$\text{Arithmetic mean} = \frac{10.1 + 9.98}{2}$$

$$= 10.04 \text{ ohms}$$

25. The bridge is in balanced condition. If all the resistance are increased by the same factor the bridge will remain balanced. Hence, V_{out} is zero.

26. In parallel $C = C_1 + C_2$

$$= \frac{C_1 C_2}{C_1 + C_2}$$



In present case total capacitance

$$= 2 + [2/3] = 2.66 \mu\text{F}$$

27. A full wave factor rectifier type meter for measuring sinusoidal current or voltage indicates 1.11 times the means value. i.e., form factor = $[V_{\text{rms}}/V_{\text{mean}}]$. For the this given wave the mean value is 100 V itself. Therefore, the meter will indicate, RMS value $100 \times 1.11 = 100 \times 1.11 = 111 \text{ V}$

29. $P = I^2 R$

$$\frac{\Delta I}{I} = \frac{0.02}{2} \times 100\% = 1\%$$

$$\frac{\Delta R}{R} = \frac{0.2}{100} \times 100\% = 0.2\%$$

$$P = I^2 R$$

$$\Delta P = 2\Delta I R + 2\Delta I^2$$

$$\frac{\Delta P}{P} = \frac{2\Delta I R}{I^2 R} + \frac{\Delta I^2}{I^2 R}$$

$$= \frac{2\Delta I}{I} + \frac{\Delta R}{R}$$

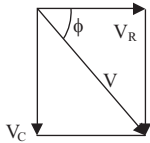
$$\therefore \frac{\Delta P}{P} = \frac{2\Delta I}{I} + \frac{\Delta R}{R}$$

$$= 2 \times 1 + 0.2 = 2.2\%$$

$$\text{Or, } \Delta P = (2^2 \times 100) \times 2.2\% = 400 \times [2.2/100] = 8.83$$

$$\text{Hence, } P = (400 \pm 8.8 \text{ W})$$

30.



$$\cos \phi = \frac{V_R}{V_C} = \frac{1R}{[I/\omega C]} = RC \omega$$

$$\therefore R = \frac{\cos \phi}{C\omega} = \frac{\cos \theta}{2\pi fC}$$

$$31. R_T = (R_1 + R_2) \pm (\delta R_1 + \delta R_2)$$

$$R_T = (528 + 325) \pm (5 + 3)$$

$$= (853 \pm 8) \text{ ohm.}$$

$$32. \left(R_x + \frac{1}{j\omega C_x} \right) \left(\frac{R_b}{1 + j\omega R_b C_b} \right) = R_c \cdot \frac{1}{j\omega C_a}$$

$$\text{or } R_b (1 + j \omega R_x C_x)$$

$$= R_c \cdot \frac{C_x}{C_a} (1 + j \omega R_x C_b)$$

$$\text{Equating the real parts: } C_x = R_b \cdot [C_a/R_c]$$

$$\text{Equating the imaginary parts: } R_x C_x =$$

$$R_c [C_x/C_a] C_b$$

$$\text{or } R_x = R_c \cdot [C_b/C_a]$$

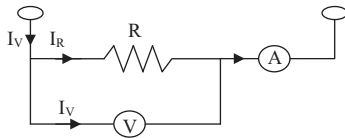
$$33. V_1 = -\frac{1}{10K\Omega} \times 10 K\Omega = -1 \text{ Volt}$$

$$V_0 = \left(\frac{-1}{10(1+\delta)} + \frac{1}{10(1-\delta)} \right) \times 10 = +2\delta$$

$$[\delta \ll 1]$$

34. As the resistance of ammeter is very low and hence, it may result in the damage of due the high current.

35.



$$R_A = 0.01\Omega; R_V = 2000 \Omega$$

$$I_R = 2A; V_R = V_V = 180 \text{ V}$$

$$I_A = I_R + I_V; I_R = I_A - I_V$$

$$\text{Since, } I_V = \frac{180}{2000}$$

$$\therefore I_R = 2 - \frac{9}{100} = 1.91 \text{ A}$$

$$\text{Since, } 1.91R = 180$$

$$\therefore R = 94.24 \Omega$$

$$\text{Error} = \frac{\text{True value} - \text{measured value}}{\text{measured value}}$$

$$\therefore \text{Error} = \frac{94.24 - 90}{90} \times 100 = 4.71\%$$

$$36. \text{ Since, } R_T = \frac{4 \times 0.05}{4.05} + 6 = 6.05\Omega$$

$$\therefore I_T = \frac{1000}{6.05} \text{ A}$$

$$\therefore V_T = \frac{1000}{6.05} \times 0.05 = 8V$$

37. Upper trace represent setting of CRO

Lower trace is display value to be measured

$$2 \text{ divisions} \rightarrow 5 \text{ V P-P}$$

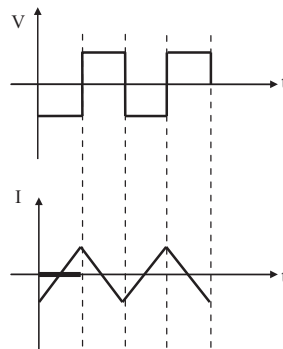
$$3 \text{ divisions} \rightarrow \frac{3 \times 5}{2} = 7.5 \text{ P-P}$$

$$\text{Frequency} = 1 \text{ kHz, } T = 1 \text{ ms}$$

Division on x-axis = 4 represent setting

Result, 8 division on x-axis = 2ms

38.



If we consider both the waves we, can see positive power and negative power in each cycle is equal

Therefore, Net power = 0

40. As per the rule of bridge to obtain the balance if one arm contains a series combination then its opposite arm has to be a parallel combination of the same components in other arm.

41. In balanced condition current through G (Galvanometer) is zero, therefore voltage across 200Ω resistance

$$V = \frac{200}{2800 + 200 + 200} \times 3.2$$

$$= \frac{200 \times 3.2}{3200} = 200 \text{ mV}$$

$$42. V_A = \frac{R}{2R} \times 10 = 5V$$

$$V_B = \frac{1}{j\omega C} \times 10$$

$$R + \frac{1}{j\omega C}$$

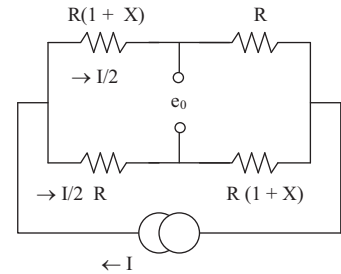
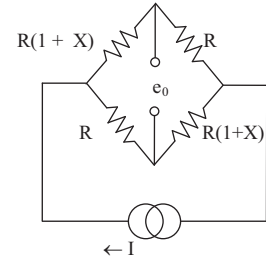
$$= \frac{1}{j\omega RC + 1} \times 10 = \frac{10}{1+j}$$

$$\text{Since } \frac{X_c}{R} = 1 \Rightarrow \frac{1}{j\omega RC} = 1$$

$$V = V_A - V_B = 5 - \frac{10}{1+j} = \frac{5+5j-10}{1+j}$$

$$= \frac{5(j-1)}{1+j} = 5V$$

43.



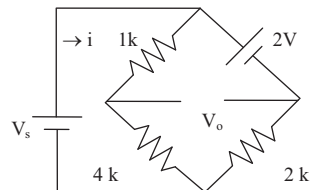
I divides equally as resistance in two parallel branches are same

$$e_0 = \frac{I}{2} \times R(1+X) - \frac{I}{2} R$$

$$e_0 = \frac{I}{2} [R - RX - R]$$

$$44. T = 200 - 40 - 40 = 120^\circ\text{C}$$

46.



In balanced condition

$$V_{AB} = V_{AB} = 2r = I \times 1K$$

$$I = \frac{2}{1K} = 2 \text{ mA}$$

$$V_{AD} - V_{DC} = 2V + 2 \times 2K = 2 + 4 = 6V$$

48. $A_d = 1$

Full scale deflection = 1 mA

$$V_0 = 1 \text{ mA} \times 10 = 10 \text{ mV}$$

$$V_2 = V_0 = 10 \text{ mV}$$

49. Time base = 100 $\mu\text{s}/\text{cm}$
 Time period = 10 $\mu\text{s}/\text{cm} \times 10 \text{ cm} = 100 \mu\text{s}$
 Frequency = $[1/T] = [1/(100 \times 10^{-6})]$
 = 10 kHz

Second Method

Screen diameter = 10 cm
 Time base = 10 $\mu\text{s}/\text{cm} = 1 \mu\text{s}$
 Signal display on screen = 10 cm $\times$ 10 $\mu\text{s}/\text{cm}$
 Frequency = $\frac{1}{t} = \frac{1}{100 \times 10^{-6}} = 0.1 \times 10^6$
 = 10 kHz

result in the damage of due the high current.

50. $f = \left(\frac{1}{T}\right) = \left(\frac{1}{1 \times 10^{-6}}\right) = 1 \text{ MHz}$
51. Semi conductor strain gauge have a gauge factor about ± 130 .
52. Change in resistance $\Delta R = G E R$.
 Where G = gain factor = 2; $R = 100$
 Strain, $\varepsilon = \frac{\text{stress}}{\text{Modulus}} = \frac{s}{E} = \frac{1050}{2.1 \times 10^6}$

$$\Delta R = 2 \times \frac{1050}{2.1 \times 10^6} \times 100 = 1 \Omega$$

Second Method

Modulus of Elasticity (E)

Stress = $E \times$ strain

$$S = E \times \varepsilon \Rightarrow \varepsilon = \frac{S}{E} = \frac{1050}{2.1 \times 10^6}$$

Gauge factor (G_f) = 2; $S = 1050 \text{ kg}/\text{cm}^2$

Strain $\varepsilon = [\Delta L/L]$

$$\varepsilon = 1$$

$$E = 2.1 \times 10^6 \text{ kg}/\text{cm}^2$$

$$L = 1000 \Omega$$

We have gauge factor

$$G_f = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon}$$

$$\Delta R = \varepsilon \times G_f \times R = \frac{1050}{2.1 \times 10^6} \times 2 \times 1000$$

$$\Delta R = 1 \Omega$$

53. Time to reach equilibrium conditions
 = $5\tau = 10\text{s}$
 $\therefore$ time constant $\tau = [10/5] = 2 \text{ s}$
 Now $\theta = \theta_0 [1 - e^{(-t/\tau)}]$

$$\frac{\theta}{\theta_0} = 1 - e^{(-t/\tau)}$$

The time to read half of the temperature difference can be calculated as

$$0.5 = 1 - e^{(-t/2)}$$

$$t = 1.39 \text{ s}$$

Time to read the half of temperature difference is 1.39s.

54. Sound pressure
 $= 20 \log_{10} \frac{\text{Given pressure in N/m}^2}{\text{Reference pressure in N/m}^2} \text{ db}$

$$\text{or, } 20 \log \left(\frac{P}{P_0} \right) = 90$$

$$\text{or, } \log_{10} \left(\frac{P}{P_0} \right) = 4.5$$

$$\left(\frac{P}{P_0} \right) = 10^{4.5} = 316227$$

$$P = P_0 \times 316227.77 = 2 \times 10^{-5} \times 316227.77$$

$$= 0.632 \text{ N/m}^2$$

$$55. C = \frac{\varepsilon A}{x}$$

$$\frac{dC}{dx} = -\frac{A\varepsilon}{x^2}$$

$$\left| \frac{dC}{dX} \right| = \frac{5 \times 10^{-4} \times 8.85 \times 10^{-12}}{4 \times 10^{10}}$$

$$= 11.06 \text{ pF/cm.}$$

$$56. \text{ Half coefficient, } K_H = \frac{V_H \cdot w}{BI}$$

Where

$$V_H = \text{Hall voltage, } (V) = -1 \times 10^{-8}$$

w = width of the slab in the direction of magnetic field, (m) = 2mm

B = magnetic flux density, (wb/m^2) = 10000 gauge

I = Current (A) = 3A

$$\therefore V_H = \frac{K_H BI}{w}$$

$$= \frac{-1 \times 10^{-8} \times 1 \times 3}{2 \times 10^{-3}} = 1.5 \times 10^{-5} \text{ V}$$

$$57. \text{ Gauge factor } K = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\text{Strain}}$$

$$= \frac{1/125}{4000 \times 10^{-6}} = \frac{0.008}{4000 \times 10^{-6}}$$

$$= \frac{8}{4 \times 10^6 \times 10^{-6}} = 2$$

$$58. \text{ Span} = X_{\max} - X_{\min}$$

$$\text{Span} = 1000^\circ\text{C} - 400^\circ\text{C} = 600^\circ\text{C}$$

$$\text{Dead-zone} = \frac{0.125}{100} \times 600 = 0.75^\circ\text{C}$$

59. In resistance type flow measuring device, flow rate is equal to

$$Q = C_d M E A \sqrt{[(2g/\omega) (P_1 - P_2)]}$$

$$Q = C_d M E A \sqrt{\frac{2g}{\omega} \cdot (P_1 - P_2)}$$

$(P_1 - P_2) \rightarrow$ Pressure different w/m^2

$C_d \rightarrow$ Coefficient of discharge
 $M \rightarrow$ Velocity approach factor
 $E \rightarrow$ Constant for flow rate charge due to temperature
 $\omega \rightarrow$ Specific wa of fluid
 $A \rightarrow$ Cross-sectional are of throat

60. $G_f = 2$, $R = 125 \Omega$, $L = 1 \text{ meter}$,
 $\Delta L = 0.005 \text{ m}$.

The Change in resistance will be given by

$$G_f = \frac{\Delta R/R}{\Delta L/L} \text{ or, } 2 = \frac{\Delta R}{125} \times \frac{1}{0.005}$$

$$\text{Hence, } \Delta R = 1.25 \Omega$$

61. Mass $m = 0.05 \text{ kg}$.

Spring constant $K = 3 \times 103 \text{ N/m}$

Displacement $X = \pm 1 \text{ mm}$.

$$\text{Hence, acceleration, } a = \frac{F}{m} = \frac{K \times X}{m}$$

$$= \frac{3 \times 10^3 \times 1 \times 10^{-3}}{0.05} = 60 \text{ m/s}^2$$

Second Method

Mass, $M = 0.05 \text{ kg}$

Spring constant $K = 3 \times 103 \text{ N/m}$

Displacement $X = \pm 1 \text{ mm}$

$$\text{Natural frequency, } \omega_n = \sqrt{\frac{K}{m}}$$

$$= \sqrt{\frac{3 \times 103}{0.05}} = 245 \text{ rad/s}$$

maximum acceleration $m = \omega^2 \times X$

$$= - (245)^2 \times 1 \times 10^{-3}$$

$$= 60 \text{ m/s}^2$$

$$62. \frac{\Delta R}{R} = \frac{13.3}{128}$$

$$\frac{\Delta L}{L} = \frac{1.6}{24}$$

$$\text{Gauge factor } (G_f) = \frac{\Delta R/R}{\Delta L/L}$$

$$= \frac{13.3}{128} \times \frac{24}{1.6} = 1.2$$

63. Absolute error = 1% of FSD

$$\pm \frac{1}{100} \times 1000 = \pm 10 \text{ W}$$

$$\text{Relative error} = \frac{\text{absolute error}}{\text{true value}} \times 100$$

$$= \frac{\pm 10 \text{ W}}{100 \text{ W}} \times 100 = \pm 10\%$$

$$64. \text{ Gauge factor} = \frac{\Delta R/R}{\text{Strain}} = \frac{\Delta R/R}{\Delta l/l}$$

$$= \frac{240 \times (10^{-6}/120)}{1 \times 10^{-6}} = \frac{240 \times 10^{-6}}{120 \times 10^{-6}} = 2$$

65. % Harmonic Distortion

$$D_A = \sqrt{\frac{E_2^2 + E_3^2 + E_4^2 + \dots}{E_1^2}} \times 100$$

$$= \frac{\sqrt{(6\sqrt{2})^2 + (8\sqrt{2})^2}}{200\sqrt{2}} \times 100$$

$$= \frac{\sqrt{72 + 128}}{200\sqrt{2}} \times 100$$

$$= \frac{\sqrt{200}}{200\sqrt{2}} \times 100$$

$$= \frac{10\sqrt{2}}{200\sqrt{2}} \times 100 = 0.05 \times 100 = 5\%$$

66. Nyquist sampling rate $f_s \geq 2f_m$

Minimum bandwidth in bits

$$= (1/2) (\text{bits per sample}) \times \text{number of samples}$$

$$= \frac{1}{2} n \times 2f_m = nf_m$$

$$67. 99\% = \frac{99}{100}$$

$$\frac{E_1}{E_2} = \frac{99}{100} = \frac{Z_L}{Z_L + 100 \text{ K}\Omega}$$

$$\Rightarrow Z_L = 10 \text{ M}\Omega$$

68. Correction Factor

It is defined as a factor by which the actual wattmeter reading is multiplied to get the power.

Therefore,

$$\text{Correction factor} = \frac{\cos \phi}{\cos \beta \cos(\phi - \beta)} \text{ for lagging loads}$$

It is clear from the phasor diagram that on lagging loads the wattmeter will read high, as the effect of the inductance of the pressure coil circuit is to bring the pressure coil current more nearly into zero. Very serious errors may be introduced by pressure coil inductance at low power factors unless special precaution are taken.

69. Minimum sampling frequency

$$= \text{Nyquist sampling rate} = 2f_m = 2 \text{ kHz}$$

$$\text{Resolution} = 0.01\% = \frac{0.01}{100} = \frac{1 \times 10}{2^n - 1}$$

$$\Rightarrow 2^n - 1 = \frac{10 \times 100}{0.01} = 1000 \times 100 = 10^5$$

$$n \cong 14$$

$$70. \sigma_I = \sqrt{\left(\frac{\partial I}{\partial I_1}\right)^2 \sigma_{I_1}^2 + \left(\frac{\partial I}{\partial I_2}\right)^2 \sigma_{I_2}^2}$$

$$\frac{\partial I}{\partial I_1} = \frac{\partial I}{\partial I_2} = 1$$

$$\sigma_I = \sqrt{(1)^2 (1)^2 + (1)^2 (2)^2} = 2.24 \text{ A}$$

$$I = (400 \pm 2.24) \text{ A}$$

$$71. \text{Deflection, } \theta = \frac{1}{2} \frac{I^2}{K} \cdot \frac{dL}{d\theta}$$

$$\text{or } \theta \propto I^2$$

$$\frac{\theta_1}{\theta_2} = \frac{I_1^2}{I_2^2}$$

$$\text{or } \theta_2 = \left(\frac{I_2}{I_1}\right)^2 \cdot \theta_1$$

$$= 100 \left(\frac{0.5}{1}\right)^2 = 25 \text{ V}$$

72. Second Method

$$\text{No of revolutions} = K \times P \times t$$

$$\therefore 5 = 1200 \times P \times \frac{75}{3600}$$

$$\Rightarrow P = 200 \text{ W}$$

74. Voltage developed, $V = g \cdot p$

$$g = \frac{V}{p}$$

$$v = 58 \times 10^{-3}$$

$$= 58 \text{ mV}$$

$$77. R_1 = \frac{100}{5 \times 10^{-3}} = 20000 \Omega$$

$$R_2 = 250 \times 100 = 25000 \Omega$$

$$R_3 = 15000 \Omega$$

Voltage developed across voltmeter will be in proportion to their resistance

$$\therefore I = \frac{120}{R_1 + R_2 + R_3} = 2 \text{ mA}$$

$$\therefore V_1 = 2 \times 10^{-3} \times 20000 = 40 \text{ V}$$

$$\therefore V_2 = 2 \times 10^{-3} \times 25000 = 50 \text{ V}$$

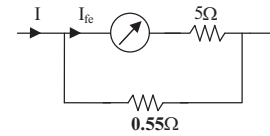
$$\therefore V_3 = 2 \times 10^{-3} \times 15000 = 30 \text{ V}$$

$$78. G = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}} = \frac{\frac{0.15}{250}}{15 \times 10^{-6}} = 4.0$$

79. A three digit display on a digital voltmeter for 0-1V range will be able to indicate values from zero to 999mV, with smallest increment or resolution of 1 mV. In practice a fourth digit usually capable to the left of indicating either 0 or 1 only is placed to the left of active digits. This permits going above 999 to 1999 to give overlap between ranges for convenience. This is called over ranging. This type of

display is known as a $3\frac{1}{2}$ digit display.

80.



$$I_{fe} = I \times \frac{0.55}{5 + 0.55}$$

$$\text{or } I = I \times \frac{1}{10}$$

$$\Rightarrow I = 10 \text{ mA}$$

81. Voltage drop per unit length

$$= 1.45/50 = 0.029 \text{ V/cm}$$

Voltage drop across 70 cm length

$$= 0.029 \times 70 = 2.03 \text{ V}$$

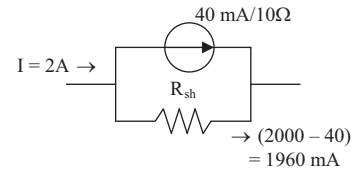
 $\therefore$ Current through resistor

$$= \frac{2.03}{1 \Omega} = 2.03 \text{ A}$$

82. Initial resistance = $20000 \times 100 = 2 \text{ M}\Omega$ Final resistance = $20000 \times 1000 = 20 \text{ M}\Omega$ $\therefore$ Series resistance = $20 - 2 = 18 \text{ M}\Omega$ 83. $T = 6 \times 30 \times 10^{-6} = 36 \mu\text{s}$

$$f = \frac{1}{36 \times 10^{-6}} = 5.55 \text{ kHz}$$

84.



$$40 \times 10 = 1960 R_{sh}$$

$$R_{sh} = [40/196] = 0.2041 \text{ ohm}$$

Second Method

 $I \rightarrow$ Current to measurement $I_m \rightarrow$ Full scale deflection current movement

$$m = \left(\frac{I}{I_m}\right)$$

$$R_{sn} = \frac{R_m}{m-1} = \frac{10}{\left(\frac{2}{40 \times 10^{-3}}\right) - 1} = \frac{10}{49}$$

$$= 0.2041 \Omega$$

$$85. F = \frac{1}{4\pi\epsilon_0} \times \frac{Q^2}{r^2}$$

$$4\pi\epsilon = \left(\frac{Q^2}{Fr^2}\right)$$

$$= \frac{Q^2}{M \cdot L \cdot T^{-2} \cdot L^2} = M^{-1} L^{-3} T^{+2} Q^{+2}$$

CHAPTER 7

LEVEL 1

1. Case 1: For two diode rectifier →

$$PIV = 2V_m$$

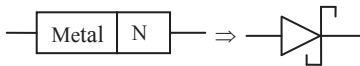
- Case 2: For four diode rectifier →

$$PIV = V_m.$$

2. In RC coupled amplifiers, the capacitor coupling is used between the two transistor amplifier stage. In this the bandwidth is limited by bypass and coupling capacitors at the low frequency end and shunt capacitor i.e. inter electrode capacitor and stay shunt capacitor effect at the high frequency end.

3. **Schottky diode** form with metal like, Gold, silver or platinum on one side of the junction and doped silicon (N-type) on the other side.

When Schottky diode is unbiased, free electron on the n side are in smaller orbits than the electron on the metal side. This difference in orbit size is called the Schottky barrier.

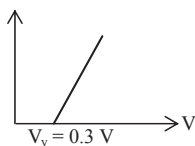


When the diode is forward biased, free electron on the N side can gain enough energy to travel in larger orbits. Because of this free electron can cross the junction and enter the metal, producing a large forward current. Since the metal has no holes there is no charge storage and no recovery time.

The lack of charge storage means that the Schottky can switch off faster than ordinary diode

Semiconductor material used is N type

Silicon—Easier to fabricate—Used X based and below frequency GaAs—lower noise.



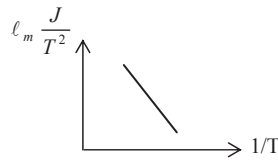
Current density

$$J = 120 \times 10^4 T^2$$

$$e \left(-11600 \frac{E_w}{T} + 0.44 \frac{J_E}{T} \right)$$

$$J = 120 \times 10^4 T^2 E^{-k/T}$$

$$\ell n \frac{J}{T^2} = -K/T.$$



- Has no depletion layer
 - Has metal semiconductor junction
 - Has fast recovery time
 - Is also called hot carrier diode
 - Can easily rectify high frequency signal
 - No minority carrier in reverse biased condition.
 - Low forward resistance due to large contact area between ordinary diode semiconductor and metal so lest noise.
4. The function of bleeder resistance in filter circuit is to:
1. Maintain minimum current necessary for optimum inductor filter operation.
 2. Work as voltage divider in order to provide variable output form the supply.
 3. Provide discharge to capacitors so that output becomes zero when the circuit has been de-energised.
5. **Chebyshev filter** is constant-k filter that achieves sharp frequency cut-off at the expense of amplitude ripple in the passband.

Butterworth Filter is a filter that has essentially flat amplitude response in the passband and an attenuation rate beyond cutoff of 6 dB per octave for a single-pole filter.

6. Current Gain Darlington pair = $h_{fe} (1 + h_{fe})$.

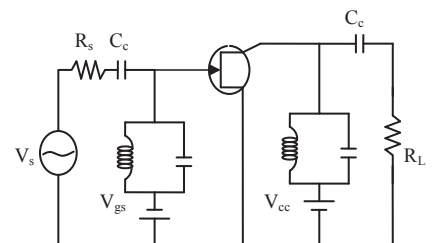
$$7. V_{dc} = V_m - V_r = V_m - \frac{I_{dc}}{4 f C}$$

The ripple is seen to vary directly with the ripple low current I_{dc} and also inversely with the capacitance. Hence, to keep the ripple low and ensure good regulation, very large capacitance (of the order of tens of microfarads) must be used. The most common type of capacitor for this rectifier application is the electrolytic capacitor. This capacitors are polarized, and care must be taken to

insert them into the circuit with the terminal marked + to the positive side of the output.

8. The function of bleeder resistance in filter circuit is to:
1. *Maintain minimum current necessary for optimum inductor filter operation.
 2. Work as voltage divider in order to provide variable output form the supply.
 3. Provide discharge to capacitors so that output becomes zero when the circuit has been de-energized.
9. A Class B amplifier is one which the operating pointing is at an extreme end of its characteristic so that the quiescent power is very small. Hence either the quiescent current or the quiescent voltage is approximately zero. If the signal voltage is sinusoidal, amplification takes place for only one-half a cycle. For example, if the quiescent output-circuit current is zero, this current will remain zero for one-half a cycle.
10. $A_{vf} = \frac{A_v}{1 + kA_v}$.
14. In all case, no frequency component of audio signal is to be supposed for Hi-Fi system. Therefore, class B amplifier are only used in Hi-Fi system.
17. **Tunned amplifier**

To provide gain at particular frequency tuned circuit are used at the input and output terminal. It is operated on RF frequency. The effective Q of the resonant circuit is to be high enough so the V_o consist only the direct voltage and fundamental component of signal i.e. of to eliminate the harmonics.



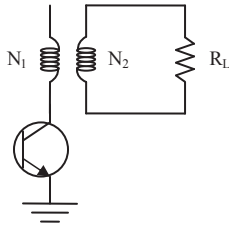
Function of the resonant circuit are:

1. To provide the correct load impedance
2. To reject the unwanted Harmonic
3. To couple the power to the load

24. Due to doping with small amount of Boron, number of hole will increase.

Since $n_n \times n_p = n_i^2 \Rightarrow n_n$ will decrease

27.



Transfer coupled amplifier give impedance matching

Effective input resistance

$$R'_L = \left(\frac{N_2}{N_1} \right)^2 R_L$$

This avoided the power loss and gives maximum power transfer to load and increases the efficiency to 50%.

32. Case 1: For two diode rectifier $\rightarrow$

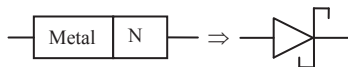
$$PIV = 2 V_m$$

Case 2: For four diode rectifier $\rightarrow$

$$PIV = V_m$$

33. In RC coupled amplifiers, the capacitor coupling is used between the two transistor amplifier state. In this the bandwidth is limited by bypass and coupling capacitors at the low frequency end and shunt capacitor i.e. inter electrode capacitor and shunt capacitor effect at the high frequency end.
34. **Schottky diode** form with metal like, Gold, silver or platinum on one side of the junction and doped silicon (N-type) on the other side.

When Schottky diode is unbiased, free electron on the n side are in smaller orbits than the electron on the metal side. This difference in orbit size is called the Schottky barrier.

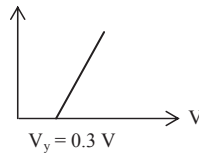


When the diode is forward biased, free electron on the N side can gain enough energy to travel in larger orbits. Because of this free electron can cross the junction and enter the metal, producing a large forward current. Since the metal has no holes there is no charge storage and no recovery time.

The lack of charge storage means that the Schottky can switch off faster than ordinary diode

Semiconductor material used is N type

Silicon—Easier to fabricate—Used X based and below frequency GaAs—lower noise.



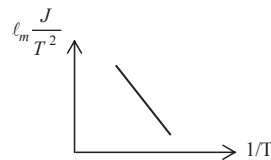
Current density

$$J = 120 \times 10^4 T^2$$

$$e(-11600 E_w/T + 0.44 J_E/T)$$

$$J = 120 \times 10^4 T^2 E^{-k/T}$$

$$\ell n \frac{J}{T^2} = -k/T$$



- Has no depletion layer
- Has metal semiconductor junction
- Has fast recovery time
- Is also called hot carrier diode
- Can easily rectify high frequency signal
- No minority carrier in reverse biased condition.
- Low forward resistance due to large contact area between ordinary diode semiconductor and metal so less noise.

35. The function of bleeder resistance in filter circuit is to:

1. Maintain minimum current necessary for optimum inductor filter operation.
2. Work as voltage divider in order to provide variable output from the supply.
3. Provide discharge to capacitors so that output becomes zero when the circuit has been de-energised.

36. **Chebyshev filter** is constant-k filter that achieves sharp frequency cut-off at the expense of amplitude ripple in the passband.

Butterworth Filter is a filter that has essentially flat amplitude response in the passband and an attenuation rate beyond cutoff of 6 dB per octave for a single-pole filter.

37. Current Gain Darlingtion pair = $h_{fe} (1 + h_{fe})$.

38. Tunnel Diode/ESAKI DIODE

- If the concentration of impurity atom is greatly increased from its normal value 1 part in 10^8 to 1 part in 10^3 -device characteristic are totally change.
- It is fabricated from Ge or GaAs.
- The width of junction barrier varies as $1/\sqrt{n}$ where n = impurity concentration, due to high doping thin barrier result. There is large probability that an electron will penetrate through the barrier even the barrier potential is not able to prevent it. This is called tunneling and these high impurity density diodes are called tunnel diodes.

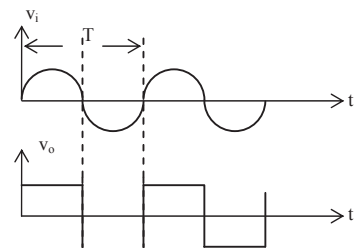
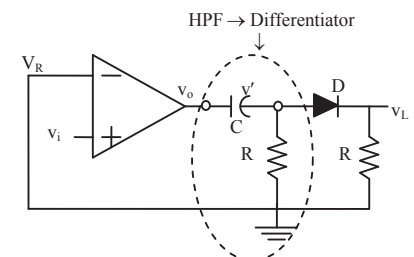
39. Feature of CE amplifier:

1. The current gain is high (h_{fe}).
2. Voltage gain is high.
3. Input impedance is medium.
4. Output impedance is medium.
5. Since voltage gain and current gain both are simultaneously high, this configuration is always used as an amplifier.

40. In an RC coupled amplifier, the gain decreases in the frequency response due to the device junction capacitor at high frequency and coupling capacitor at low frequency

41. The total range ΔV_o over which the output can follow input is $R_c I_o$ and is therefore adjustable through an active load through an adjustments of I_o , where $I_o = I_{c1} + I_{c2}$.

42. Zero-crossing deflector.



A zero-crossing detector converts a sinusoid V_i into a square wave V_o .

Zero-crossing Detector: If V_R is set equal to zero, the output will respond almost discontinuously every time the input passes through zero. Such an arrangement is called a zero-crossing detector.

43. There is no current in a class B system if there is no signal as compared to class A system.

The dc components of the output current of the two transistor opposes each other in the transformer. This eliminates the tendency of the output core of the transformer to saturate. Therefore losses in the transformer are minimize which increases the efficiency

44. Feature:

- The current gain is high (h_{fe}).
- Voltage gain is high.
- Input and output current are out of phase by 180° .
- The input and output voltage are out of phase by 180° .
- Input impedance is medium.
- Output impedance is medium.
- Since voltage gain and current gain both are simultaneously high, this configuration is always used as an amplifier.

45. **Photodiodes:** If a **reverse-biased pn junction** is illuminated that is, exposed to incident light the photons impacting the junction cause covalent bonds to break, and thus electron hole pairs are generated in the depletion layer. The electric field in the depletion region then sweeps the liberated electrons to the n side and the holes to the p side, giving rise to a reverse current across the junction. This current, known as **photocurrent, is proportional to the intensity of the incident light**. Such a diode, called a photodiode, can be used to convert light signals into electrical signals.

Light-Emitting Diodes (LEDs)

The light-emitting diode (LED) performs that inverse of the function of the photodiode, it converts a forward current into light. The reader will recall that in a **forward-biased pn junction**, minority carries are injected across the junction and diffuse into the p and n region. The diffusing minority carriers then recombine with the majority carriers. Such recombination can be made to give rise to light emission. This can

be done by fabricating the pn junction using a semiconductor of the type known as **direct-bandgap materials**. **Gallium arsenide** belongs to this group and can thus be used to fabricate light-emitting diodes.

The light emitted by an LED is proportional to the number of recombination that take place, which in turn is proportional to the forward current in the diode.

46. 1. The dc components of the output current of the two transistor oppose each other in the transformer. This eliminates the tendency of the output core of the transformer to saturate. Therefore, the losses in the transformer are minimized.
2. If quiescent current is low. Hence efficiency is maximum i.e., $25\pi = 75.5\%$

$$\eta = 25\pi \left(1 - \frac{V_C(\min)}{V_{CC}} \right)$$

- 47.

BJT	FET
1. High voltage gain	Low voltage gain
2. Low current gain	High current gain
3. Low input and output impedance	High input and output impedance
4. Medium noise generation.	Low noise generation.
5. (Gain $\times$ Bandwidth) high	(Gain $\times$ Bandwidth) medium
6. Current source	Voltage controlled

48. Emitter η :

This is the ratio of injection current across the emitter junction to the total emitter.

$$\text{For PNP } r_o = \frac{E_{pE}}{I_{pE} + I_{nE}} = \frac{I_{pE}}{I_E}$$

Base transport factor:

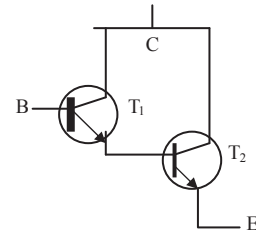
It is ratio of injected carrier current reaching junction to the injected carrier current at J_n , J_E

$$\text{For PNP, } B^T = \frac{I_{pcl}}{I_{pE}}$$

49. % Regulation $\frac{V_{NL} - V_{FL}}{V_{FL}}$

50. CC-CC (Darlington Pair)

The CC amplifier has high input impedance as a single transistor; to increase the input impedance still further we use the Darlington emitter follower, which is CC-CC amplifier. The two transistors form a composite pair. This can be considered as single transistor with only three external lead.



Assuming two transistors are having same h_{fe}

$$\frac{I_C}{I_{B1}} = h_{fe} \times h_{fe} = h_{fe}^2; \quad A_v \approx 1$$

Input Impedance

$$R_i = h_{ie1} + (h_{fe1} + 1) h_{ie2}$$

$$R_i = 2h_{ie2} (h_{fe1} + 1)$$

assuming $h_{ie1} = h_{ie2} = h_{ie}$

51. The gain of a bipolar transistor drops at high frequencies due to inter electrode transistor capacitances.
54. A push-pull amplifier may be operated as class-A, class-AB or class B. When the large amounts of power are required, the amplifier is designed for class-B operation.
55. As α is same for both Si and Ge, germanium because of greater mobility of electrons can operate at much higher frequency than silicon.
56. A Darlington pair circuit, has two emitter followers (cc - cc) in cascade. An emitter follower is the common collector circuit. In this case, current gain is high $A_i = (1 + h_{fe}) h_{fe}$.
57. To avoid the voltage drop at the source
61. Monostable multivibrator is a pulse generator.
62. FET exhibits lower offset voltage at zero drain current, and hence makes an excellent signal chopper.
63. Input impedance is very high and output impedance is quite low (but not zero).

64. The coupling capacitors C_s and C_c and emitter bypass capacitors C_e determine the low frequency response.

65. Class A → efficiency 25%

Class B → efficiency 50%

Class C → maximum efficiency 78%.

$$66. Q = \frac{f_o}{f_{c2} - f_{c1}} = \frac{f_o}{BW}$$

68. Amplitude of oscillations is limited by the onset of non-linearity of operation in the active devices associated with the amplifier.

69. The essential blocks of phase lock loop (PLL) are phase detector, amplifier, low-pass filter and voltage controlled oscillator.

70. FET has negative temperature coefficient of drain current. The principal reason is that the mobility decreases with increasing temperature.

71. The sequence of these rectifier circuit in decreasing order of their ripple factor is:

1. Half-wave rectifier without filter → 1.21
2. Full-wave rectifier without filter → 0.482
3. Full-wave rectifier with series inductance filter → $\frac{\sqrt{2}}{3} \frac{R_L}{X_L}$
4. Full-wave rectifier with capacitance filter → $\frac{1}{4\sqrt{3}} \times \frac{1}{f_{RC}}$

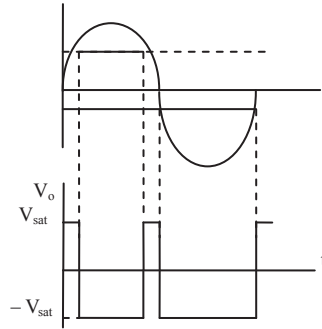
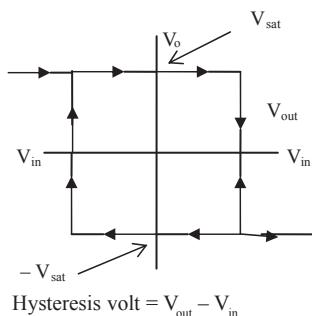
72. For small load currents (say upto 50 mA), this type of filter is preferred

77. Voltage gain, taking the effect of finite gain A_{v0}

$$A_{vf} = -\frac{\omega_1}{RC} A_{v0} \frac{1}{(S + A_{v0} \omega_1) \left(S - \frac{1}{RC A_{v0}} \right)}$$

79. An op-amp possess very large input (ideally infinite) and very small output resistance (ideally zero).

80. Input is sine wave output is square wave



1. Schmitt
2. Clipper if gain to kept very high sine input turns into square wave.
3. Monostable always needs negative going pulse input for its operation.

81. For current shunt amplifier

$$Z_{if} = \frac{Z_i}{1 + \beta A}; \quad Z_{of} = Z_o (1 + \beta A)$$

$$82. Z'_{out} = \frac{Z_{out}}{(1 + K A_v)}$$

Output resistance is inversely proportional to h_{fe} of the shunt transistor.

83. Feature of CC amplifier

1. Highest current gain $(1 + h_{fe})$
2. Voltage gain always less the unity (lowest)
3. Input and output current are in phase.
4. Input and output voltage are in phase.
1. Input impedance is the highest of all the three configurations.
2. Output impedance is the lowest of the three configurations.
3. Used at place where the impedance conversion from a high value to low value is desired. Therefore it is always used as last stage of any audio amplifier where its output impedance is matched to low impedance speaker to transfer maximum amount of power.
4. Since it is having high input impedance therefore it can be used as a buffer amplifier, which draw negligible current & does not load the previous stage.
5. Z_{in} depend upon the load.

85. The hysteresis phenomenon in Schmitt Trigger is:

1. In the inverted mode, the circuit triggers at a higher voltage for increasing signals than for decreasing signals.
2. Slowly varying signals are converted to output waveform with abrupt changes at two specified levels of input signals.

88. Due to Reverse bias of collector junction the depletion layer in base region increase and base width decreases.

LEVEL 2

1. Transistor at Low Frequencies

Parameter	CE	CC	CB
h_i	1.1 k Ω	1.1 K Ω	20 Ω
h_r	2.5×10^{-4}	1	3×10^{-4}
h_f	50	-51	-0.99
$[1/h_o]$	40 k Ω	40 k Ω	2 M Ω

Approximate values for different quantities using approximate equivalent model are given as follows:

	CB	CC	CE	CE with Re
A_i	$\frac{h_{fe}}{1 + h_{fe}}$	$1 + h_{fe}$	$-h_{fe}$	$-h_{fe}$
Z_{in}	$\frac{h_{fe}}{1 + h_{fe}}$	$\frac{h_{ie} + (1 + h_{fe}) R_L}{h_{ie}}$	$\frac{h_{ie}}{(1 + h_{fe}) R_e}$	$\frac{h_{ie} + (1 + h_{fe}) R_e}{(1 + h_{fe}) R_e}$
A_v	$\frac{h_{fe} R_L}{h_{ie}}$	$1 - \frac{h_{ie}}{Z_{in}}$	$\frac{-h_{fe} R_L}{h_{ie}}$	$\frac{-h_{fe} R_L}{Z_{in}}$
Z_{out}	∞	$\frac{R_s + h_{ie}}{1 + h_{fe}}$	∞	∞
Z'_{out}	R_L	$Z_{out} \parallel R_L$	R_L	$ R_L$

Equivalent Circuit of FET at High Frequencies

$V_{CE} = 5$ volts, $I_c = 100 \mu A$, $A_i = 100$

$$A_i = \frac{I_c}{I_B} \Rightarrow I_B = \frac{I_c}{A_i} = \frac{100 \mu A}{100}$$

$$I_B = 1 \mu A$$

$$R_c = \frac{V_{CE}}{I_c} = \frac{5}{100 \mu A} = 50 \text{ k}\Omega$$

$$h_r A_i Z_L = 2.5 \times 10^{-4} \times 100 \times 50 \times 10^3 = 1250 \Omega$$

$$h_i = 1100 \Omega$$

$$h_i + h_r A_i Z_L = 1100 + 1250$$

$$= 1250 \Omega$$

$$= 2350 \text{ K} \text{ Closer to } 2400 \Omega$$

2. A class A stage has maximum efficiency of 25% for (RC coupled) or 50 percent for transformer coupled. Class B has a maximum efficiency of 78.5%.

$$3. A_v = \frac{R_s}{\frac{\mu + 1}{\mu} R_s + \frac{1}{g_f s}} \approx \frac{g_f s R_s}{1 + g_f s R_s}$$

The approximation holds when $\mu \gg 1$ which is usually the case for an FET

$$\begin{aligned}
 6. \quad \beta &= \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = \frac{0.98}{0.02} = 49 \\
 I_C &= \beta I_b + (1+\beta) I_{CO} \\
 &= 49 \times 100 \times 10^{-6} + (1+49) \times 6 \times 10^{-6} \\
 &= (4900 + 300) 10^{-6} \\
 &= 5200 \times 10^{-6} \\
 &= 5.2 \text{ mA}
 \end{aligned}$$

7. With negative feedback, the upper cut-off frequency increase and become $(1+|A||B|)$ times the original cut-off frequency

$$\begin{aligned}
 f_{uf} &= \left(1 + \frac{500}{100}\right) \times 60 \\
 &= 360 \text{ kHz}
 \end{aligned}$$

8. Given $A_d = 50$, $A_c = 0.2$

$$\therefore \text{CMRR} = \frac{|A_d|}{|A_c|} = \frac{50}{0.2} = 250$$

9. For FET CD/source follower

Output impedance

$$\begin{aligned}
 Z_o &= R_s \parallel r_d \parallel 1/g_m \\
 &= 1 \text{ k}\Omega \parallel 50 \text{ k}\Omega \parallel 0.5 \text{ k}\Omega \\
 &= \frac{1 \text{ k}\Omega \times 50 \text{ k}\Omega \times 0.5 \text{ k}\Omega}{1 \times 50 + 50 \times 0.5 + 1 \times 0.5} \\
 &= \frac{25 \text{ G}\Omega}{50 \text{ M} + 25 \text{ M} + 0.5 \text{ M}} \\
 &= \frac{25 \text{ G}\Omega}{75.5 \text{ M}\Omega} \\
 &= \frac{1000 \text{ G}\Omega}{3} \\
 &= 300 \Omega
 \end{aligned}$$

10. $A_v = 50$, $k = \frac{1}{10}$

$$Z_{in} = 1 \text{ k}\Omega$$

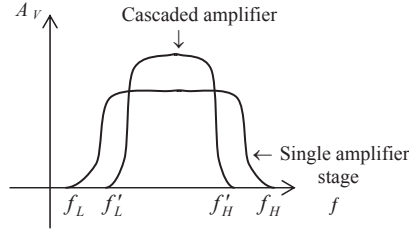
$$Z_{out} = 40 \text{ k}\Omega$$

$$A_{vf} = \frac{A_v}{1+k A_v} = \frac{50}{1+50 \times \frac{1}{10}}$$

$$Z_{inf} = Z_{in} (1+k A_v) = 1 \times 6 = 6 \text{ k}\Omega$$

$$Z_{ouf} = \frac{Z_{out}}{1+k A_v} = \frac{40}{6} = 6.66 \text{ k}\Omega$$

11. In cascaded stage, the lower cut-off frequency. Increase and higher cut off frequency decrease and over gain of amplifier increases.



$$f_L(\text{cascade}) = \frac{f_L}{\sqrt{2^{(1/n)} - 1}}$$

$$\text{and } f_H(\text{cascade}) = f_H \sqrt{2^{(1/n)} - 1}$$

For $n = 2$

$$f_H(\text{Given}) = 2 \text{ MHz and } f_L(\text{Given}) = 30 \text{ Hz.}$$

$$f_H(\text{cascade}) \approx 3.1 \text{ MHz; } f_L(\text{cascade}) \approx 19.3 \text{ Hz}$$

12. When the diode conducts, the voltage across the load and hence across the capacitor increases to V_m .

14. We use *voltage-shunt feedback for a transistor phase-shift oscillator*.

We imagine the loop broken at the base between B_1 and B_2 , but in order not to change the load in on the feedback network, we place R_i then B_2 to ground. If we assume a current I_b to enter the base

$$\text{at } B_1, \text{ then loop gain} = \frac{x'_f}{x_i} = \frac{-x_f}{x_i} = -\beta A$$

for the loop gain and figure we have $x_f = -I_3$ and $x_i = I_b$. The loop current

$$\text{gain equals } -\frac{x_f}{x_i} = \frac{I_3}{I_b} \text{ and is found by}$$

writing Kirchhoff's voltage equation for the three meshes. The Berkhausen condition that the phase of $\frac{I_3}{I_b}$ must equal zero

leads to the following expression for the frequency of oscillation:

$$f = \frac{1}{2\pi RC} \frac{1}{\sqrt{6+4k}}$$

where $k = \frac{R_c}{R}$. The requirement that the

magnitude of $\frac{I_3}{I_b}$ must exceed unity in order of oscillation to start leads to the inequality.

$$h_{fe} > 4k + 23 + \frac{29}{k}$$

The value of k which gives the minimum h_{fe} turns out to be 2.7, and for this optimum value of $\frac{R_c}{R}$, we find

$h_{fe} = 44.5$. A transistor with a small-signal common-emitter short-circuit current gain less than 44.5 cannot be used in this phase-shift oscillator.

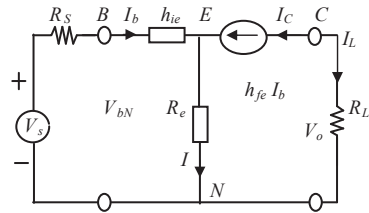
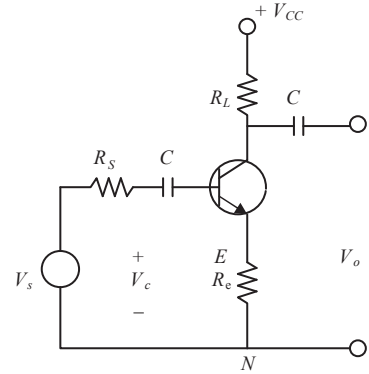
17. The transistor is in saturation. Have V_{ce} is above 0.2 volt.

18. $I_{CEO} = I_{CO}$

$$I_{CEO} (1+\beta) I_{CBO}$$

$$\begin{aligned}
 I_{CEO} &= \frac{I_{CO}}{1-\alpha} \\
 &= \frac{0.5}{1-0.995} = 100 \mu\text{A}
 \end{aligned}$$

19. CE amplifier with emitter resistance R_E



It is very important to stabilize the voltage amplification of an amplifier, i.e., it becomes independent or h -parameter

$$I = I_b + h_{fe} I_b = (1 + h_{fe}) I_b$$

$$1. \quad A_i = \frac{I_L}{I_b} = \frac{-h_{fe} I_b}{I_b} = -h_{fe} \dots\dots$$

unaffected

$$\begin{aligned}
 2. \quad Z_{in} &= \frac{V_b}{I_b} = \frac{h_{ie} I_b + R_e I}{I_b} \\
 &= \frac{h_{ie} I_b + (1+h_{fe}) I_b \cdot R_e}{I_b} \\
 &= h_{ie} + (1+h_{fe}) R_e
 \end{aligned}$$

Z_{in} increased by a factor of $(1+h_{fe}) R_e$

$$3. \quad A_v = A_i \cdot \frac{Z_L}{Z_{in}}$$

$$= \frac{-h_{fe} \cdot R_L}{h_{ie} + (1 + h_{fe}) R_c} \Rightarrow \text{decreased}$$

$$4. \quad Z_{out} = \infty, Z_{out} = \infty \mid \mid R_L = R_L$$

$$20. \quad A_f = \frac{A}{1 + AB}$$

$$\frac{\partial A_f}{\partial A} = \frac{(1 + AB) - AB}{(1 + AB)^2} = \frac{1}{(1 + AB)^2}$$

$$\therefore \frac{\partial A_f}{\partial A} = \frac{\partial A}{(1 + AB)^2} \times \frac{(1 + AB)}{A} = \frac{\partial A}{(1 + AB)^2}$$

$$\text{or } \frac{\partial A_f}{\partial A} = \frac{\frac{\partial A}{1 + AB}}{1 + AB}$$

$$\text{Given that, } A = -1000$$

$$B = -0.1 \text{ and } \frac{\partial A}{A} = 20\% = 0.2$$

$$\therefore \frac{\partial A_f}{A_f} = \frac{0.2}{1 + 100} = 0.2\%$$

$$21. \text{ For half wave rectifier, } PIV = V_m$$

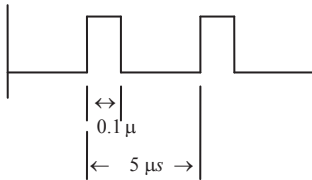
$$V_{rms} = \frac{V_m}{2}$$

$$\text{and } V_m = 10 \times 2$$

$$= 20 \text{ V}$$

$$23. \quad f_s = 200 \text{ kHz}$$

$$\Rightarrow T_s = \frac{1}{f_s} = \frac{1}{200 \text{ kHz}} = 5 \mu\text{s}$$



$$\text{duty cycle} = \frac{T_{ON}}{T_{total}} = \frac{0.1 \mu\text{s}}{5 \mu\text{s}}$$

$$= \frac{1}{50} = 2\%$$

$$24. \quad h_{ib} = \frac{h_{ie}}{1 + h_{fe}} = \frac{10 \text{ k}\Omega}{1 + 100}$$

$$25. \text{ KVL in Collector loop}$$

$$V_c = I_c \times R_c + V_{ce(sat)}$$

$$5 = I_c \times 1 \text{ K} + 0.3$$

$$I_c = \frac{5 - 0.3}{1 \text{ K}} = 4.7 \text{ mA}$$

$$V_{DS} = 20 - 4 \times (2.5 + 1.5) = 4 \text{ V}$$

26. PIV is the maximum voltage which can be applied to a particular diode under reverse bias condition before break down occurs

When diode is forward biased, capacitor gets charged to V_m , when diode is reverse biased capacitor behaves like a battery with voltage V_m in series with ac source.

27. Upper cut-off frequency

$$f_{c2}' = f_{c2} \sqrt{2^{1/n} - 1}$$

For interacting stages, if the frequencies are not widely separated, the equivalent f_H is given (to within 10%) by

$$\frac{1}{f_H} = 1.1 \sqrt{\frac{1}{f_{21}^2} + \frac{1}{f_{22}^2}}$$

$$= 1.1 \sqrt{\frac{1}{5^2} + \frac{1}{(3.3)^2}}$$

$$= 1 + \sqrt{\frac{1}{25} + \frac{1}{10}}$$

$$= 1.1 \sqrt{\frac{2+5}{50}} = \sqrt{\frac{7}{50}}$$

$$f_H = \frac{1}{1.1} \times \sqrt{\frac{50}{7}}$$

$$= \frac{1}{1.1} \sqrt{7.14}$$

$$= \frac{1}{1.1} \times 2.6 = 2.2 \approx 2 \text{ MHz}$$

$$28. \quad A_i = 100, R_i = 10 \text{ k}\Omega, R_L = 1 \text{ k}\Omega$$

$$\frac{V_o}{V_i} = A_i \frac{R_L}{R_i} = 100 \times \frac{1}{10} = 10$$

$$A_v (\text{dB}) = 20$$

$$= 20 \log_{10} \left| \frac{V_o}{V_i} \right| \text{ dB} = 20 \log_{10} 10$$

$$= 20 \text{ dB}$$

$$29. \quad \text{CMRR} = \left| \frac{A_d}{A_c} \right| = \frac{10^5}{0.01} = 10^7$$

30. The Barkhausen Criterion

The condition for sinusoidal oscillation can be expressed as:

$$T(j\omega_o) = 1, \angle T(j\omega) = -180^\circ$$

1. Two conditions must be satisfied by a circuit to sustain oscillation.

2. The phase shift through the amplifier; and feedback network must be 360° as T includes a minus sign which is equivalent to 180° of phase shift.

3. The magnitude of the gain of the amplifier and feedback network must be unity.

$T(j\omega) = -1$ known as Barkhausen Criterion.

4. Barkhausen Criterion is equivalent to stating that with both the phase margin and gain margin are zero. So the phase and gain, crossover frequencies are equal.

5. In every practical oscillator the loop gain is slightly larger than unity and the amplitude of the oscillations is limited by the on-set of non-linearity.

31. In an n-type material

$$N_D = \frac{4.4 \times 10^{22}}{10^6} / \text{cm}^3$$

$$\text{From mass action law } n.p = n_i^2$$

$$\therefore p = \frac{(2.5 \times 10^{13})^2}{4.4 \times 10^{16}} = 1.4 \times 10^{10} / \text{cm}^3$$

32. For intrinsic semiconductor $n = p$

$$\text{Conductivity, } \sigma = q(\mu_n n + \mu_p p)$$

$$= 1.6 \times 10^{-19} (1.5 \times 10^{-16} \times 0.13 + 1.5 \times 10^{16} \times 0.05) = 4.32 \times 10^{-4} (\Omega \cdot \text{m})^{-1}$$

33. Apply Maximum Power Transfer Theorem

$$R_S + jX_S = R_L + jX_L$$

$$R_L = R_o = 4\Omega = R_S$$

$$P_{\max} = I^2 \cdot R_L = \left(\frac{6}{4+4} \right)^2$$

$$= \frac{9}{16} \times 4 = \frac{9}{4}$$

$$= 2.5 \text{ watt}$$

34. For a sinusoidal signal of general form $V_i = V_m \sin \omega t$ the maximum voltage rate of change can be shown to be

$$\left. \frac{dV_i}{dt} \right|_{\max} = V_m \omega \cos \omega t$$

To prevent distortion at the output the rate of change must also be less than the slew rate, i.e.,

$$V_m 2\pi f \leq SR$$

$$\Rightarrow \frac{0.5}{10^{-6}} \geq V_m 2\pi f$$

$$f \leq \frac{SR}{V_m 2\pi} \text{ Hz.}$$

assuming voltage gain = 1

$$\text{For } V_m = 2\sqrt{2} V$$

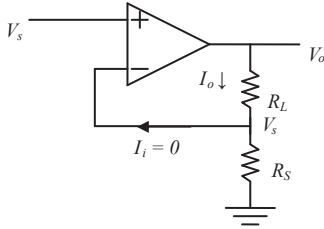
$$\text{and } SR = 0.5 V / \mu s$$

Input

$$f_{\max} = \frac{0.5}{10^{-6} \times 2 \times \pi \times 2 \times \sqrt{2}} = 28.13 \text{ kHz}$$

$$\approx 30 \text{ kHz.}$$

35.



Since $Z_{in} \rightarrow \infty$ of op-amp

Then, $I_i = 0$

$$I_o = \frac{V_s}{R_S}$$

Second Method

Since this is non-inverting amplifier whose gain is

$$V_o = \left(1 + \frac{R_L}{R_S}\right) V_s$$

$$I_o = \frac{V_o - V_s}{R_L}$$

36. Apply superposition to get output

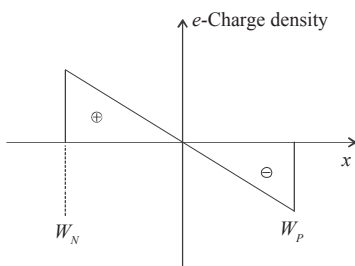
$$\text{For input } V_{s1} \rightarrow \text{output } V_{o1} = \left(1 + \frac{2R}{R}\right) V_{s1}$$

$$\text{For input } V_{s2} \rightarrow \text{output } V_{o2} = -\frac{2R}{R} V_{s2}$$

$$\Rightarrow V_o = V_{o1} + V_{o2} = 3V_{s1} - 2V_{s2}$$

37. Linearly graded function

$$W_B = W_N + W_P$$



$$C = \frac{\epsilon A}{W_B}$$

$$W_B \propto V_j^{1/3}$$

$$\Rightarrow C_T \propto \frac{1}{3\sqrt{V_j}}$$

$$\Rightarrow C \propto V_j^{-1/3}$$

$$38. \text{ Flat band voltage} = \frac{3 \times 10^{-4}}{300 \times 10^{-6}}$$

$$\{1 - (-0.85)\} = 1.85 V$$

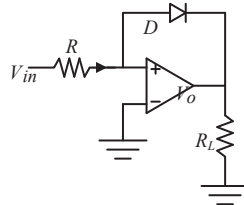
39. This is a half wave rectifier circuit

$$V_{av} = \frac{1}{2\pi} \int_{\pi}^{2\pi} V_m \sin \omega t d\omega t$$

$$= \frac{1}{2\pi} V_m \left[-\cos 2\omega t \right]_{\pi}^{2\pi} = -\frac{V_m}{\pi}$$

40. Capacitor would act as battery of $(-V_m)$ volt

41. Circuit behaves as logarithmic amplifier



When $V_{in} < 0$; diode is off, Op-amp behaves as comparator. At this time

$$V_o = +V_{sat}$$

• When $V_{in} > 0$ diode is ON

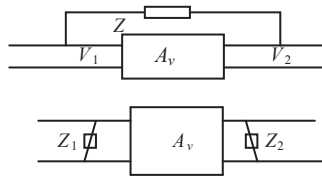
$$V_o = -0.7 V$$

• For small range of V_{in} . It behaves as logarithmic amplifier.

$$V_o = 2.3 \frac{KT}{q} \log_{10} \left(\frac{V_{in}}{R_L I_o} \right)$$

43. According to Miller's theorem

It states that if an impedance Z is connected between the input and output terminal of network between which there is voltage gain A_v , the same effect can be held by removing Z and connecting an impedance Z_1 at the input and Z_2 at output.



$$Z_1 = \frac{Z}{1 - A_v}; \quad Z_2 = \frac{Z}{1 - \left(\frac{1}{A_v}\right)}$$

$$Y_1 = Y(1 - A_v); \quad Y_2 = [1 - (1/A_v)]$$

$$C_{in} = C(1 - A)$$

44. Noise decrease in negative feed back amplifier

Noise level in output

$$N_f = \left(\frac{N}{1 + \beta A_v} \right) = \frac{100 mV}{1 + \frac{1}{60} \times 240}$$

$$= \frac{100 mV}{5} = 20 mV$$

45. For difference amplifier, Given

$$A_d = 10^3, \quad \text{CMRR} = 100$$

$$V_c = \frac{1}{2}(120 + 80) = 100 \times 10^{-6} V$$

$$V_d = 120 - 80 = 40 \times 10^{-6} V$$

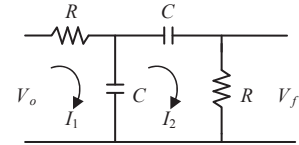
$$V_o = A_d V_d + A_c V_c$$

$$V_o = A_d V_d \left[1 + \frac{1}{\text{CMRR}} \frac{V_c}{V_d} \right]$$

$$V_o = 10^3 \times 40 \times 10^{-6} \left(1 + \frac{1}{100} \times \frac{10^{-4}}{40 \times 10^{-6}} \right)$$

$$V_o = 41 mV$$

46. KVL in first loop



$$V_o = I_1 \left(R - \frac{j}{\omega C} \right) + I_2 \left(-\frac{j}{RC} \right) \quad (1)$$

KVL in second loop

$$0 = I_2 \left(R - \frac{2j}{\omega C} \right) - I_1 \left(-\frac{j}{RC} \right) \quad (2)$$

$$I_2 \left(R - \frac{2j}{\omega C} \right) = -I_1 \frac{j}{RC}$$

$$\text{or } I_2 (1 - 2jX) = I_1 jX \quad (3)$$

$$\text{Where, } X = \frac{1}{\omega RC}$$

From equation (1) and (3)

$$= \frac{V_o}{V_f} = \frac{V_o}{I_2 R} = 3 + \frac{j(1 - X^2)}{X}$$

$$= \frac{3X + j(1 - X^2)}{X}$$

For phase shift to be 180° (for oscillation)

$$\tan^{-1} \left(\frac{1 - X^2}{3X} \right) = \pi$$

$$\Rightarrow \frac{1-X^2}{3X} = 0$$

$$\Rightarrow X = 1$$

$$\text{i.e., } \omega = \frac{1}{RC}$$

$$\frac{V_o}{V_f} = 3 \quad \text{at } \omega = \frac{1}{RC}$$

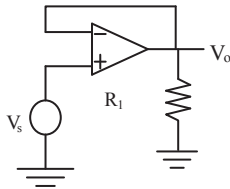
$$\therefore \beta = \frac{V_f}{V_o} = \frac{1}{3}$$

Loop gain $\beta A \geq 1$ (for oscillations)

$$\therefore A_{\min} = \frac{1}{\beta} = 3$$

Note: If you remember such type of feed back circuit are used for Wien bridge oscillator whose gain $A_v \geq 3$

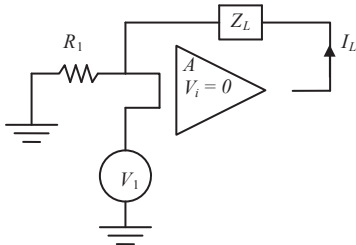
47. Unity Follower



The output signal is in phase with the input signal and of same magnitude.

Input impedance is very high, so it provides very good isolation between stages.

48. Due to Virtual ground short-circuit equivalent circuit is



Voltage at $XV_{R1} = V_i$

$$\therefore \text{current } i_L = \frac{V_i}{R_1}$$

49. In cascading upper cut-off frequency decrease and given by

$$f_u^* = f_u \sqrt{2^{1/n} - 1}, \text{ where } n = \text{number of state}$$

In present case $n = 2$ given than

$$f_u^* = f_u \sqrt{2 - 1}$$

50. In cascading lower cut off frequency increases and given by

$$f_L^* = \frac{f_L}{\sqrt{2^{1/n} - 1}}, \text{ Where } n = \text{number of state}$$

In present case $n = 2$

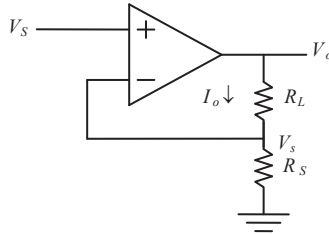
$$\text{Therefore } f_L^* = \frac{f_L}{\sqrt{2 - 1}}$$

51. Regulation Factor

$$S = \frac{\Delta V_o}{\Delta V_i} \bigg|_{\Delta I_L = 0}$$

At Constant temperature $\Delta T = 0$, **regulation should be low for good regulation.**

52.



Using Virtual ground concept

$$I_o = \frac{V_o - V_s}{R_L}$$

$$\text{Where } V_o = \left(1 + \frac{R_L}{R_s}\right) V_s$$

$$\Rightarrow I_o = \frac{V_s}{R}$$

Second Method

For Ops-amps

$$Z_{in} \rightarrow \infty$$

$$I_{in} \rightarrow 0$$

$$\text{Then } I_o = \frac{V_s}{R_s}$$

53. According to mass action law.

$$n \cdot p = n_i^2$$

$$n = \frac{(1.5 \times 10^{10})^2}{2.25 \times 10^{15}} = 10^5 / \text{cc}$$

54. In a transistor, I_{CBO} is equal to I_{CO} and doubles for every ten degrees rise in temperature

$$\begin{aligned} I_C &= \beta I_B + I_{CEO} \\ &= \beta I_B + (1 + \beta) I_{CBO} \end{aligned}$$

$$= \beta I_B + (1 + \beta) I_{CO}$$

$$I_{CEO} = (1 + \beta) I_{CBO}$$

$$= \left(\frac{1}{1 - \alpha}\right) I_{CBO}$$

$$I_C = \beta I_B + (1 + \beta) I_{CO}$$

$$= \beta I_B + (1 + \beta) I_{CBO}$$

$$= \beta I_B + I_{CBO}$$

$$\text{Where } B = \frac{\alpha}{1 - \alpha}$$

$$I_{CEO} = (1 + \beta) I_{CBO}$$

$$= \left(\frac{1}{1 - \alpha}\right) I_{CBO}$$

55. The dynamic transfer characteristic for a transistor is required is represented by

$$i_c = A_1 i_b + A_2 i_b^2$$

Where A_1 and A_2 are constants. If input

signal $i_b = I_1 \cos \omega_1 t + I_2 \cos \omega_2 t$

The output is

$$i_c = A_1 (I_1 \cos \omega_1 t + I_2 \cos \omega_2 t)$$

$$+ A_2 (I_1 \cos \omega_1 t + I_2 \cos \omega_2 t)$$

$$= A_1 (I_1 \cos \omega_1 t + I_2 \cos \omega_2 t)$$

$$+ A_2 \left(I_1^2 \cos^2 \omega_1 t + I_2^2 \cos^2 \omega_2 t \right. \\ \left. + 2 I_1 I_2 \cos \omega_1 t \cdot \cos \omega_2 t \right)$$

$$[\because \cos 2\theta = \cos^2 \theta - \sin^2 \theta]$$

$$= 2 \cos^2 \theta - 1$$

$$\cos^2 \theta = \frac{1 + \cos 2\theta}{2}$$

$$\text{and } 2 \cos x \cdot \cos y = \cos(x + y) + \cos(x - y)$$

$$\text{Therefore, } i_c = A_1 I_1 \cos \omega_1 t + A_1 I_2 \cos \omega_2 t$$

$$+ \frac{A_2}{2} + \frac{A_2}{2} \cos 2\omega_1 t + \frac{A_2}{2} + \frac{A_2}{2} \cos 2\omega_2 t$$

$$+ A_2 \cos(\omega_1 + \omega_2)t + A_2 \cos(\omega_1 - \omega_2)t$$

Hence output contain DC,

$$\omega_1, \omega_2, 2\omega_1, 2\omega_2$$

$$(\omega_1 + \omega_2), (\omega_1 - \omega_2)$$

$$56. r_d = \frac{\eta V_T}{I_o e^{V_T \eta / V_T}}$$

$$\text{or } \frac{r_{d,2}}{r_{d,1}} = \frac{e^{V_1 \eta / V_T}}{e^{V_2 \eta / V_T}}$$

$$\text{Therefore, } \frac{1000 \cdot r_{d,1}}{r_{d,1}} = e^{(V_1 - V_2) \eta / V_T}$$

$$\text{Therefore, } \log_e 10^3 = |V_1 - V_2| \cdot \frac{\eta}{V_T}$$

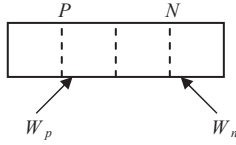
$$\text{Or } |V_1 - V_2| = (\log_e 10^3) \text{ for } \eta = 1$$

57. For Full wave rectifier

$$PIV = 2V_m = 200V$$

58. Two common emitter stage given phase shift of 360° by one RC coupled circuit given phase shift of 45° at each 3 db frequency i.e., $(0 + 45^\circ)$ and $(180 + 45^\circ) = 225^\circ$

59.



$$N_a W_p = N_d W_n$$

$$= 4 N_a W_n$$

$$\text{Or, } [W_p/W_n] = 4$$

$$\text{Or, } [W_n/W_p] = 0.25.$$

Higher the doping level lesser the width of depletion layer.

60. Silicon sample having electron phosphorous 10^{16} group 5 donor, boron 2×10^6 group 3 acceptor

$$N_a - N_d = 10^{16}$$

Material is p type.

61. Donor concentration $N_D = 10^{19}/\text{cm}^3$

Excess electron concentration i.e.,

$$\Delta n \text{ hole concentration} = 10^{15}/\text{cm}^3$$

Generation rate of minority Carrier =

$$\frac{\text{Excess hole concentration}}{\text{Hole life time}}$$

$$= \frac{10^{15}}{10 \times 10^{-6}} = 10^{20} \text{ e.h pair/cm}^3/\text{s}.$$

62. The diode behave as capacitor. Therefore voltage across the capacitor and current through the inductor does not change instantaneously.

63. The ratio $[\sigma/\omega\epsilon]$ is a good measure of the conductivity of the material. Hence

$$\frac{\sigma_o}{\omega\epsilon} = \frac{10^6}{10 \times 10^9 \times 10 \times 8.85 \times 10^{-12}}$$

$$= 1.12 \times 10^6 \gg 1$$

Hence the material is a good conductor.

64. Mobility $\mu = [v/E]$; drift velocity $V_d = 1/(20 \times 10^{-6})$

$$\mu = \frac{1}{20 \times 10^{-6}} \times \frac{1}{10}$$

$$= 0.5 \times 10^4$$

$$= 5000 \text{ m}^2/\text{volt-sec}.$$

65. Electrons are promoted from the valence band to the conduction band by thermal energy. $F(E)$ is essentially 0 in the valence band and 1 throughout the conduction band. Fermi level is inside the conduction band: $P(E) = 1$.

66. Because the emitter is the most heavily doped region in the transistor. It is about 40 to 50% of BV_{CBO} i.e., $BV_{CEO} < BV_{CBO}$

i.e., if doping is more then break up point is less.

67. $np = n_i^2$ its mass action law

$$n = \frac{n_i^2}{P} = \frac{1.5 \times 10^{10}}{2.25 \times 10^{15}}$$

$$= \frac{2.25 \times 10^{20}}{2.25 \times 10^{15}} = 10^5/\text{cm}^3.$$

68. $C_i = \frac{C_o}{[1 + V_R/V_T]^n}$

where, $n = 1/2$ for abrupt junction.

70. $n \cdot p = n_i^2 = \frac{2.25 \times 10^{20}}{2.25 \times 10^{15}}$

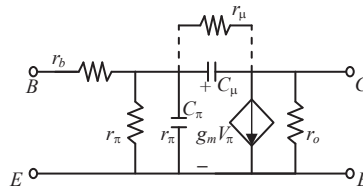
71. Given n_i and p_i are electron and hole concentration in an intrinsic semi-conduction.

Material is doped with p-type material

$$n_i \rightarrow n \text{ and } p_i \rightarrow p$$

Therefore $n p = n_i p_i$ in general $n_i = p_i$
 $= n_i^2$ i.e., mass action less.

72.



$$f_B = \frac{1}{h_{fe}} = \frac{g_m}{2\pi(C_u + C_\pi)} ; C_u = C_{bc}$$

$$C_\pi = C_{be}$$

$$f_T \text{ of a BJT is related as } f_1$$

$$= [g_m/(2\pi(C_\pi + C_\mu))]$$

73. Static characteristic of forward biased p-n junction,

$$I = I_o [\exp [(V_d/V_T) - 1]$$

$$\log [(I/I_o) + 1] = (V_d/V_T)$$

i.e., Straight line is log I vs V.

74. The Fourier coefficient A_0, A_1, A_2, A_3 ---

Where A_0 ---- represent dc value

A_1 ---- Fundamental

A_2 ---- 2nd Harmonic

A_3 ---- 3rd harmonic

$$\text{Harmonic distortion } D_2 = \left[\frac{A_2}{A_1} \right];$$

$$D_3 = \left[\frac{A_3}{A_1} \right]$$

$$D_4 = \left[\frac{A_4}{A_1} \right]$$

Total harmonic distortion (THD) or distortion factor

$$D = \sqrt{D_2^2 + D_3^2 + D_4^2}$$

$$= \sqrt{(A_2/A_1)^2 + (A_3/A_1)^2 + (A_4/A_1)^2}$$

$$= \frac{\sqrt{A_2^2 + A_3^2 + A_4^2}}{A_1}.$$

76. Let majority carrier be electron: $n = 5 \times 10^{20}$

$$\text{Intrinsic carrier } n_i = 1.5 \times 10^{16}$$

Now according to MASS-ACTION LAW

$$n p = n_i^2 ; p = \frac{n_i^2}{n} = \frac{(1.5 \times 10^{16})^2}{5 \times 10^{20}}$$

$$= 4.50 \times 10^{11}/\text{m}^3.$$

77. Conductivity $\sigma = n e \mu_n + p e \mu_p$

For N type $\sigma = n e \mu_n$

$$\text{Resistivity } \int = \left(\frac{1}{n e \mu_n} \right)$$

$$\text{Resistance of the base} = \left(\rho \frac{1}{A} \right) = \frac{1}{\sigma \cdot A}$$

$$= \frac{1}{n e \mu_n \cdot A}$$

$$= \frac{10^{-3} \cdot m}{(5 \times 10^{20} \times 1.6 \times 10^{-19} \times 1.3) \times 100 \times 10^{-6} \times 10^{-6}}$$

$$= 10^6 \text{ ohm}.$$

79. Doping $\uparrow \Rightarrow$ width of depletion layer $\downarrow$

$$\therefore N_A X_p = N_D (X - X_p)$$

Where, X = Total depletion width

$$\text{Or, } 9 \times 10^{16} X_p = 1 \times 10^{16} (3 - X_p)$$

$$\text{Or, } 9 X_p = 3 - X_p$$

$$\text{Or, } 10 X_p = 3$$

$$X_p = [3/10] = 0.3 \mu\text{m}.$$

80. Conductivity for N-type Semi conductor is

$$\sigma_N = e N_D \mu_n$$

$$N_D = \frac{\sigma_N}{\mu_n e} = \frac{1}{0.5 \times 1.6 \times 10^{-19} \times 1250}$$

$$= 1 \times 10^{16}/\text{cm}^3.$$

81. $C_j \propto \left(\frac{1}{\sqrt{V_{bi} + V_R}} \right) = i.e. \propto \left(\frac{1}{V_j} \right)$

$$\frac{C_2}{C_1} \propto \sqrt{\frac{1}{4}} \Rightarrow C_2 = 0.5 \text{ PF}.$$

82. For N-Channel MOSFET

V_T = Threshold voltage

N_D = Donor concentration

C = Capacitance

t = thickness = d

$$V_T \propto \sqrt{N_D}$$

$$V_T \propto \frac{1}{C} = \frac{1}{(\epsilon_o A)/d} \propto \frac{1}{t}$$

$$V_T \uparrow \propto V_D \uparrow \text{ and}$$

$$V_T \downarrow \propto t \uparrow$$

V_T of a MOS capacitor increase with increase substrate doping concentration.

$$83. E_{g(ev)} = \left[\frac{he}{\lambda} \right]$$

$$E_{g(ev)} = \frac{12400}{\lambda (A^\circ)} = \frac{12400}{0.8700 \times 10^{-6} \times 10^{-4}}$$

$$= 1.416 \text{ eV.}$$

84. Diffusion current density

$$J_n = e D_n \left(\frac{dn}{dx} \right)$$

$$\text{where, } dx = 0.5 \mu\text{m} = 0.5 \times 1000 \mu\text{m}$$

$$dn = 10^{14}/\text{cm}^3$$

$$D_n = 25 \text{ cm}^2/\text{s}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$J_n = e \cdot D_n \cdot [dn/dx]$$

$$= 1.6 \times 10^{-19} \times 25 \times \frac{10^{14}}{(0.5 \times 10^{-6}) \times 10^3}$$

$$= 1.6 \times 50$$

$$[4 \times 8 (12)] = 2.6 \Omega.$$

87. Feature of CC amplifier

1. Highest current gain $(1 + h_{fe})$
2. Voltage gain always less the unity (lowest)

$$88. \frac{dV}{dt} = 100 \text{ m/sec} = 100 \times 10^6$$

$$f = 10 \text{ MHz}$$

$$V = V_m \sin \omega t$$

$$\frac{dv}{dt} = V_m \omega \cos \omega t$$

$$V_m \omega = 100 \times 10^6$$

$$V_m = \frac{100 \times 10^6}{\omega} = \frac{100 \times 10^6}{2\pi \times 10 \times 10^6}$$

$$= \frac{5}{\pi} \text{ volt.}$$

$$89. \text{ Given } A_{db} = 10 \log [P_o/P_i] = 60$$

$$\therefore [P_o/P_i] = 10^6$$

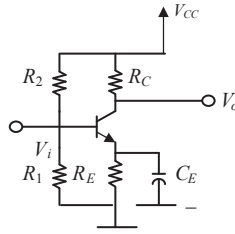
$$\therefore P_o = (10)^6 \times 2 \times 10^{-6} = 2 \text{ W.}$$

90. For CB configuration

$$h_{ib} = \frac{h_{ie}}{1 + h_{fe}} = \frac{5 \times 10^3}{100 + 1} = \frac{5000}{101} = 49.5 \Omega$$

LEVEL 3

1. This is a potential divider/self biasing.



$$R_1 || R_2 = R_B$$

Stability for self biasing circuit is given by.

$$S = \frac{(\beta + 1)R_B/R_E}{\beta + 1 + R_B/R_E}$$

For better stability S-should be minimum

$$= \frac{R_B}{R_E} \ll 1$$

2. Node 1

$$\frac{V_a - V_1}{1} + \frac{V_a - V_o}{90} = 0$$

$$\text{Or, } 91 V_a = V_o + 90 V_1 \quad (1)$$

$$V_o = -90 V_1 + 91 V_a$$

Node 2

$$\frac{V_a - V_2}{1} + \frac{V_a - V_o}{100} = 0$$

$$\frac{100V_a - 100V_2 + V_a}{100} = 0$$

$$\text{or, } V_a = [100/101] V_2$$

$$101 V_a = 100 V_2$$

From equation number (1)

$$\text{or, } V_o = -90 V_1 + \frac{100}{101} V_2 \times 91$$

$$\therefore V_1 = V_c + [V_d/2]$$

$$\text{and } V_2 = V_c - [V_d/2]$$

Hence

$$V_o = -90 [V_c + (V_d/2)] + [100/101] \times 91 [V_c - (V_d/2)]$$

$$= V_c [(9100/101) - 90] - [V_d/2] [90 + (9100/101)]$$

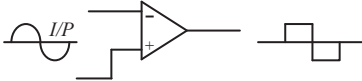
$$= V_c [10/101] - V_d [9095/101]$$

$$V_o = V_c A_c + V_d A_d$$

$$\text{Therefore, } A_c = [10/101] A_d = [9095/101]$$

$$\text{CMRR, } [A_d/A_c] = 909.5 \approx 900$$

3.



Since op amp is in open loop mode, it will give $+V$ sat or $-V$ sat i.e., square wave

But if its slew rate is high, then triangular

4. Output voltage = offset Voltage $\times$ Gain

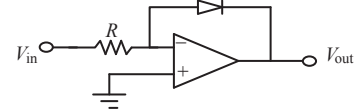
$$= V_{os} \times \frac{R_2}{R_1}$$

$$= 1 \times 10^{-3} \times \frac{10^6}{10^3} = 1 \text{ V}$$

Since offset voltage can be $\pm 1 \text{ mV}$

Therefore output voltage is $\pm 1 \text{ V}$

5.



$$i = V_{in}/R$$

$$= I_s [\exp (V_{out}/V_T) - 1]$$

$$V_{out} = V_T \log \left(\frac{V_{in}}{R \cdot I_s} + 1 \right)$$

Or, $V_T = [KT/e]$

$$V_{out} = V_T \ln [V_{in}/R \cdot I_s]$$

$$= 2.3 V_T \log_{10} [V_{in}/R \cdot I_s]$$

Thus the circuit work as logarithmic amplifier

6. Knee current is Zener diode minimum current

Hence load current I_L will be maximum.

$$I_L \text{ max} = 80 - 5 = 75 \text{ mA}$$

$$R = \frac{6}{75 \times 10^{-3}} = 80 \text{ ohm}$$

7. The output voltage, $V_o = 0$ for $V_i < 0.5 \text{ V}$

For $V_i \geq 0.5$, As the diode starts conducting,

$$\text{therefore } V_o = \frac{V_i - 0.5}{900} \times 600$$

$$\text{At } V_i = 2 \text{ volts, } V_o = \frac{2 - 0.5}{900} \times 600 = 1 \text{ V}$$

$$11. \omega = \frac{1}{(LC)} = \frac{1}{10 \times 10^{-3} \times 0.01 \times 10^{-6}} = 10^5 \text{ rad/sec}$$

For oscillation $A\beta = 1$

$$\text{or, } 1 + \frac{100 \text{ K}}{5 \text{ K}} \frac{1000}{1000 + R} = 1$$

$$\therefore = 20000 \Omega = 2 \times 10^4 \Omega$$

12. $I_m = [(9 - 6)/50] = 0.06 \text{ A} = 60 \text{ mA}$

Maximum current through zener diode =

$$\frac{300 \times 10^{-3}}{6} = 50 \text{ mA}$$

$$\therefore \text{ Minimum current through load} = 60 - 50 = 10 \text{ mA}$$

$$\text{And Maximum current through load} = 60 - 5 = 55 \text{ mA}$$

13. Without the capacitor there is a negative feedback and gain is reduced. By connecting a high value capacitor the

ac signals are by passed and gain is increased.

Before connecting capacitor, $Z_{in} = h_{ie} + (1+B) R_E$. A capacitor in shunt of high value reduces the value of R_E (almost shorts) and so decreases the input impedance

14. Gain = 6dB

$$G_{dB} = 10 \log G = 6$$

$$G = (10)^{.6} = 3.98$$

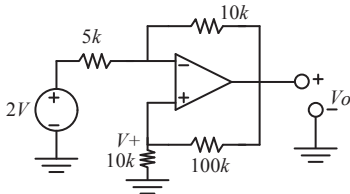
$$10 \log F = 3 \Rightarrow (10)^{[3/10]} = 2$$

$$\text{Overall Noise figure } F = F_1 + \frac{F_2 - 1}{G}$$

$$= 2 + \frac{2-1}{3.98} = 2.25$$

$$F = 10 \log 2.5 = \mathbf{3.5 \text{ dB}}$$

- 15.



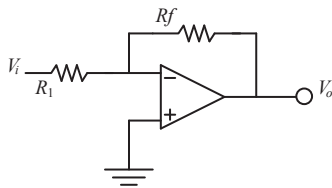
$$V_+ = [10/110] \times V_0 = [V_0/11]$$

$$\Rightarrow \frac{[(V_0/11) - 2]}{5} + \frac{[(V_0/11) - V_0]}{10} = 0$$

$$\frac{2V_0}{11} - 4 + \frac{V_0}{11} - V_0 = 0$$

$$\Rightarrow \frac{3V_0}{11} - V_0 = 4$$

$$\Rightarrow V_0 = -\frac{4 \times 11}{8} = -5.5 \text{ V}$$



$$\frac{0 - V_1}{R} + \frac{0 - V_0}{R_f} = 0$$

$$\Rightarrow \frac{V_o}{V_i} = \frac{-R_f}{R} = \frac{-R}{R} = -1$$

Second method

$$e^- = \frac{10K}{15K} \times 2 + \frac{5K}{15K} V_o$$

$$e^+ = \frac{10K}{110K} V_o$$

$$V_d = 0 \quad ; \quad e^- = e^+$$

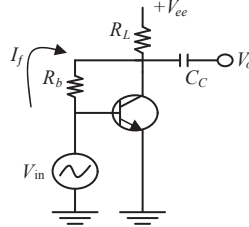
$$\text{or, } \frac{4}{3} + \frac{V_o}{3} = \frac{V_o}{11}$$

$$\text{or, } V_o [(1/3) - (1/11)] = -[4/3]$$

$$\text{or } V_o [(11 - 3)/33] = V_o [8/33] = -4/3$$

$$\text{or, } V_o = \frac{-4}{3} \times \frac{33}{8} = -5.5 \text{ V}$$

16. Voltage shunt



$$V_o \gg V_i$$

$$I_f = \frac{V_i - V_o}{R_b} = -\frac{V_o}{R_b} = K V_o$$

$$\text{Where } K = [-1/R_b]$$

Since feedback current is proportional to output voltage i.e., voltage shunt feedback

17. V_1 & V_2 have same polarity, there is drop in voltage i.e., $V_1 = 2V_2$.

18. The given figure is of cascode connection. In cascode connection overall trans conductance g is equal to trans conductance of first state. Thus it is equal to g_{m1} as proved below:

$$g_m = \frac{I_o}{V_i}$$

$$I_o \cong I_{E2} = I_{C1}$$

$$I_{C1} = \beta I_{B1} \text{ and } I_{E2} \cong I_{C1}$$

$$I_o \cong \beta I_{B1}$$

$$V_i = I_{B1} r_{\pi}$$

$$\frac{I_o}{V_i} = \frac{\beta I_{B1}}{I_{B1} r_{\pi}} = g_{m1}$$

$$19. A_{CM} = \frac{-h_{fe} \times R_L}{h_{ie} + 2(1 + h_{fe}) R_e}$$

$$= \beta R_L / R_e$$

$$\text{When } R_e \rightarrow \infty$$

$$A_{CM} \rightarrow 0$$

20. The present diagram represent Non-inverting positive feed back amplifier. In positive feed back, Ops amplifier works in saturation region $\pm V_{sat}$.

Here applied voltage is positive

$$\text{Hence, } V_o = +V_{sat} = +15 \text{ V}$$

$$21. V_o = -\frac{R_f}{R_i} V_{in}$$

$$= -\left(\frac{\omega_c}{\omega_c}\right) V_1 \sin \omega t - \left(\frac{\omega_c}{\omega_c}\right) V_2 \sin \omega t$$

$$V_o = -V_1 \sin \omega t - V_2 \sin \omega t$$

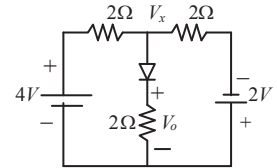
$$= -(V_1 + V_2) \sin \omega t$$

22. There is R-C, series connection in parallel with parallel R-C combination. So it is Wein bridge oscillator because R_1 and R_2 is also in parallel with them.

23. It is a differentiator

$$V_o = -R \omega C V_i = RC [dv_i/dt]$$

- 24.

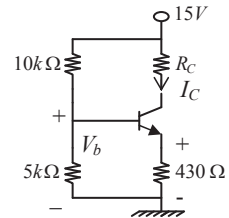


Apply KCL at Node V_x

$$\frac{V_x - 4}{2} + \frac{V_x + 2}{2} = 0$$

$$V_x = 1$$

- 25.



$$V_b = [5/(5 + 10)] \quad 15 = 5 \text{ V}$$

$$I_c = \beta I_b \quad ; \quad I_o = [I_c/\beta]$$

$$I_e = I_c + I_b = (I_c + I_c/\beta)$$

KVL in base loop

$$-5 + 0.7 + 430 [I_c/\beta + I_i] = 0$$

Since β is large therefore, $430 I_c = 4.3$

$$\Rightarrow I_c = [4.3/430] = \mathbf{10 \text{ mA}}$$

In short Method

$$V_{Th} = \frac{5}{10 + 5} \times 15 = 5 \text{ V}$$

$$R_{Th} = 5 \parallel 10 = \frac{5 \times 10}{5 + 10} = \frac{50}{15} = 3.3 \Omega$$

Since β is large $I_\beta = 0$.

$$I_c = \frac{V_{Th} - V_{BE}}{R_{Th}} = \frac{5 - 0.7}{430}$$

$$= \frac{4.3}{430} = 10 \text{ mA}$$

26. The DC input offset voltage V_{io} appears across the amplifier input and this voltage will be amplified/integrated and will appear at the output.

$$V_o (\text{off set}) = V_{io} [1 + (R_f/R)] \rightarrow \text{Feedback}$$

$$= V_{io} \times A_v - \text{Open loop.}$$

$$V_o = 5 \times 10^{-3} \times 10,000 = \pm \mathbf{50 \text{ V}}$$

But since output voltage can not exceed supply voltage i.e., $\pm 15V$ thus $V_o = \pm 15V$

27. Due to feed back delay becomes double in ring oscillator

In ring oscillator each stage propagation delay is being added up which becomes the Time period of oscillator i.e., $5 \times 100 \times 2 \text{ pSec} = 1000 \text{ pSec}$

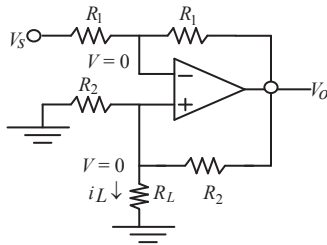
$$f = \frac{1}{T} + \frac{1}{500 \times 10^{-12}} \times \frac{1}{2}$$

$$= [1000/500] \times 10^9 = 1 \text{ GHz.}$$

28. $\frac{V_o}{V_s} = \frac{-R_f}{R_s} = \frac{-R_1}{R_1}; V_o = -V_s$

KVL, $\frac{0+V_s}{R_2} + i_L = 0$

$$i_L = -\frac{V_s}{R_2}$$



29. RC couple Amplifier

$n = 3$ stage are couple

$$f_L = f_L \sqrt{(2^n - 1)} = 20 \sqrt{(2^3 - 1)} = 20 \sqrt{2^2}$$

$$= 20 \times 2 = 40 \text{ Hz}$$

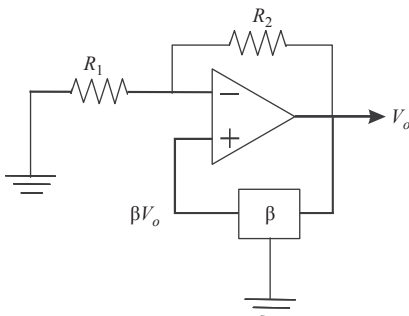
$$f_h = \frac{f_h}{(2^n - 1)} = \frac{1 \text{ KHz}}{(2^3 - 1)} = \frac{1 \text{ K}}{2^2} = \frac{1}{2}$$

$$= 0.5 \text{ KHz}$$

$$f_L' = \frac{f_L}{\sqrt{2^{1/n} - 1}}$$

$$f_h' = f_h \sqrt{2^{1/n} - 1}$$

31. There are two type of feed back applied to input. Both are to be considered



KCL at Node 1

$$\frac{\beta V_o - 0}{R_1} + \left(\frac{\beta V_o - V_o}{R_2} \right) = 0$$

$$\beta \left(\frac{1}{R_1} + \frac{1}{R_2} \right) = \frac{1}{R_2}$$

or, $\beta \left(\frac{R_1 + R_2}{R_1} \right) = 1$

or $\left(1 + \frac{R_1}{R_2} \right) = \frac{1}{\beta} = 6$

or $\frac{R_2}{R_1} = 5$

$$\Rightarrow R_2 = 5 R_1$$

32. $V_{R_{\max}} = V_{IN} - V_Z = 30V - 10V = 20V$

$$I_{R_{\min}} = I_L + I_{ZK} = (10 + 1) \text{ mA} = 11 \text{ mA}$$

$$R_{\max} = [20 \text{ V}/11 \text{ mA}] = 1800 \Omega$$

$$R \leq 1800 \Omega.$$

33. $A_v = -g_m (r_d \parallel R_D)$

$$g_m = \pm [2/V_p] \sqrt{(I_D \cdot I_{DSS})}$$

Assuming $r_d \geq 10 R_D$ then, $A_v = -g_m R_D$

$$g_m = g_{m0} [1 - (V_{gs}/V_p)]$$

$$= [2 I_{DSS}/|V_p|] \sqrt{(I_D/I_{DSS})}$$

$$V_{gs} = I_D \cdot R_s$$

$$= -2.5 \text{ k} \times 1 \text{ mA} = -2.5$$

$$g_m = [2 I_{DSS}/|V_p|] [1 - (V_{gs}/V_p)]$$

$$\frac{2 \times 10 \text{ mA}}{5} \left[1 - \left(\frac{-2.5}{5} \right) \right] = 4 \text{ mA} \times \frac{2.5}{5}$$

$$= 2 \text{ mA/V}$$

$$A_v = -g_m R_D = -2 \text{ mA/V} \times 3.0 \text{ k}\Omega = -6$$

Second Method

$$A_v = -g_m (R_D \parallel r_d)$$

$$g_m = \frac{2 I_{DSS}}{|V_p|} \left(1 - \frac{V_{GS}}{V_p} \right)$$

$$V_s = I_D R_s = 1 \text{ mA} \times 2.5 \text{ k}$$

$$= -2.5 \text{ V}$$

$$V_G = 0$$

$$V_{GS} = V_G - V_s$$

$$= -2.5 \text{ V}$$

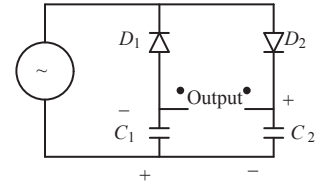
$$g_m = \frac{2 \times 10 \text{ mA}}{5} \left[1 - \left(\frac{-2.5}{-5} \right) \right]$$

$$= 2 \text{ ms}$$

$$A_v = -2 \text{ ms} \times 2 \text{ K (as } r_d \text{ is not given assume as } \infty)$$

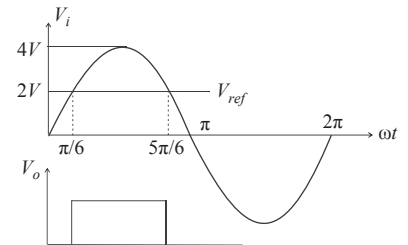
$$= -6$$

- 34.



During the positive half cycle D_2 conducts due to C_2 charged to positive V volt. During the negative half cycle C_1 gets charged to Negative V volt. So that output voltage across AB is $V + V = 2V$ Volt i.e., voltage doubler.

- 35.



The output is positive only when the reference input is greater than 2V.

$$V_i = 8 V_{pp} \text{ sinusoidal i.e.,}$$

$$= 4 \sin \omega t$$

$$\text{At } V_i = 2 \Rightarrow \sin \omega t = \frac{2}{4} = \frac{1}{2}$$

$$\Rightarrow \omega t = \sin^{-1} \frac{1}{2} = \frac{\pi}{6}$$

$$\text{Another cross over at } \pi - \frac{\pi}{6} = \frac{5\pi}{6}$$

$$\text{Duty cycle} = \frac{T_{ON}}{T}$$

$$= \frac{\frac{5\pi}{6} - \frac{\pi}{6}}{2\pi} = \frac{\frac{4\pi}{6}}{2\pi}$$

$$= \frac{1}{3}$$

36. $V_{CC} - I_C R_2 = V_{CE}$

$$R_2 = \frac{(6-3)}{1.5 \text{ mA}} V = 2 \text{ K}\Omega$$

$$I_C = I_B \beta + (1 + \beta) I_{CO}$$

$$I_{B1} = \frac{I_{C1}}{\beta}$$

$$= \frac{1.5 \text{ mA}}{150} = 0.01 \text{ mA}$$

When, $\beta = 200$

$$I_B \text{ remains same, } I_C \text{ become} = \beta_2 I_B$$

$$= 200 \times [1.5/150] \text{ mA}$$

$$V_{CC} - I_{C2} R_2 = V_{CE}$$

S.74 ■ Solutions

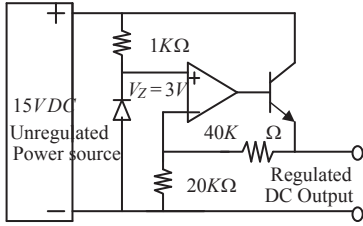
$$V_{CE2} = 6 - 2 \cdot 10^{-3} \times 2 \times 10^3 \\ = 6 - 4 = 2V$$

This operating point is (2V, 2mA)

37. $F = [1/2\pi RC \sqrt{6}]$

This is RC phase shift AF oscillator

38.



In an amp series regulator the o/p is

$$V_o = \left(1 + \frac{R_1}{R_2}\right) V_z$$

$$= \left(1 + \frac{40}{20}\right) \times 3 = 9V$$

Other way, The voltage at op-amp input

$$V_+ = V_- = V_z = 3V$$

Then, by voltage division rule

$$\left(\frac{20}{20+40}\right) V_o = 3, V_o = 9V$$

Another Approach

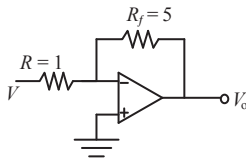
As voltage at Non inverting terminal is 3 V due to Zener diode, voltage at inverting terminal will be same as 3 V because of virtual ground concept.

∴ Current through 20 kΩ resistor is

$$\frac{3}{20k} = \frac{2}{20} mA$$

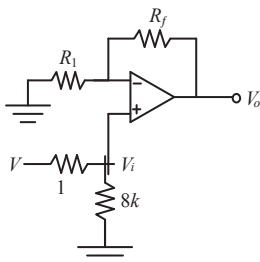
$$\therefore V_o = \frac{3}{20k} \times 60k = 9V$$

39.



Output due to -Ve terminal voltage $V_{o1} =$

$$\frac{R_f}{R_1} \times V = \frac{-5}{1} \times 2 = -10V$$



Output due to +Ve terminal voltage

$$V_{o2} = \left(1 + \frac{R_f}{R}\right) V_i$$

in present case,

$$V_i = [8/8 + 1] \times 3 = [8/3] V$$

$$V_{o2} = \left(1 + \frac{R_f}{R}\right) V_i$$

$$= [1 + 5/1] \times [8/3]$$

$$= 6 \times [8/3] = 16V$$

$$V_o (\text{Net o/p}) = V_{o2} + V_{o1} = 16 - 10 = 6V.$$

40. The combined effect of two resistor and two capacitor give a fall off rate of 40 db/decade. If is a second order LPF.

$$\text{At } \omega = \infty, C \rightarrow \text{short circuit}, \frac{V_o}{V_{in}} = 0$$

$$\text{At } \omega = 0, C \rightarrow \text{open circuit}, \frac{V_o}{V_{in}} = 1$$

41. If an amplifier has very high gain i.e., $A_v \rightarrow \infty$ then

$$A_{vf} = [-R_2/R_1] \text{ otherwise as below}$$

$$\text{Close loop Gain } A_{vf} = \frac{V_o}{V_i} = \frac{A_v}{1 + A_v K}$$

$$\text{Where, } K = \frac{R_1}{R_1 + R_f} = \frac{2}{2+8} = \frac{2}{10} = 0.2$$

$$A_{vf} = \frac{45}{1 + 45(0.2)} = \frac{45}{10} = 4.5$$

$$42. I_{max} = \frac{30-10}{20} = 1A$$

$$\frac{I_C}{I_B} = 99$$

$$I_E = I_Z + I_C$$

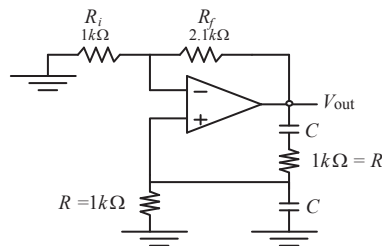
$$I_1 = I_C + I_Z = 100 I_Z$$

$$P_T = I_C V_C = 10 \times 0.99 = 9.9 \text{ watt}$$

$$P_Z = V_Z I_Z = 9.5 \times 0.01 = 95 \text{ m watt}$$

43. It is a CC amplifier. Thus gain should be nearly equal to one.

44. The given figure represent Wein Bridge oscillator



For Wein Bridge oscillator

$$\text{Frequency of oscillation } f_o = [1/2\pi RC]$$

$$\text{The ratio of } [R/R_f] \approx 2$$

Gain of amplifier $A_v \geq 3$

$$f_o = [1/2\pi RC]$$

$$\Rightarrow C = \frac{1}{2\pi} \times \frac{1}{1 \times 10^3 \times 1 \times 10^3} = \frac{1}{2\pi} \mu F$$

45. $\beta = h_{fe} = 50$

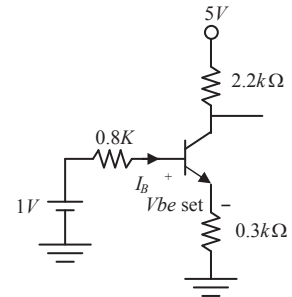
$$V_{CC} = I_C \cdot R_C + V_{CE \text{ sat}}$$

$$I_C = h_{fe} \cdot I_B$$

$$\Rightarrow I_C = \frac{3-0.2}{1k} = 2.8 \text{ mA}$$

$$I_B = \frac{2.8 \text{ mA}}{50} = 0.056 \text{ mA} = 56 \mu A$$

46.



$$R_{th} = \frac{1 \times 4}{1+4} = 0.8 \text{ K}\Omega$$

$$V_{th} = [1/5] \times 5 = 1V$$

KVL in base loop

$$-1 + 0.8 \times I_b + V_{be \text{ sat}} + 0.3 \times I_C = 0$$

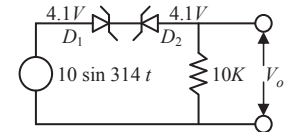
$$I_b \rightarrow 0 \text{ as } \beta \text{ is very large}$$

$$0.3 I_C = 1 - 0.7 = 0.3$$

$$I_C = 1 \text{ mA}$$

$$V_{CE \text{ sat}} = 5 - 2.2 \times 1 - 0.3 \times 1 = 2.5V$$

47.



During positive half cycle for input less than 4.1 V

$D_1 \rightarrow$ Forward biased

$D_2 \rightarrow$ Reverse biased

Current through load resistance is zero.

Thus $V_o = 0$

During positive half cycle for more than 4.1 V

$D_1 \rightarrow$ Forward biased

$D_2 \rightarrow$ Reverse biased but Zener break down take place and voltage across V_Z is 4.1 Volt.

Thus maximum voltage drop across load resistance is $= 10 - 4.1 = 5.9V$

Similarly, During the negative half cycle output is maximum to $-5.9V$

48. The input resistance R_i is effective value of parallel combination of $10k$ and input impedance of amplifier i.e.,
 $R_i = 10k \parallel \infty = 10k\Omega$

49. Since no input is applied at the input side and still an output e_o is available thus one can measure input offset current only.

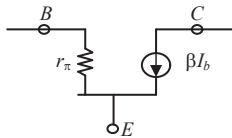
50. At 1000Hz frequency, $Z_c \rightarrow \infty$

Hence, high pass filter

Since, input is at (+) terminal, therefore

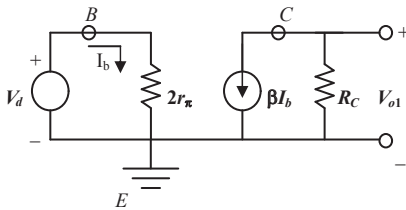
$$\omega_c = \frac{1}{RC} = \frac{1}{1 \times 10^3 \times 1 \times 10^6} \\ = 1000 \text{ rad/sec}$$

51. Equivalent circuit of BJT is



Differential mode gain (A_d):

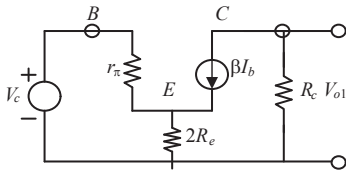
Small signal model for difference mode



$$A_d = \frac{V_{o1}}{V_d} = \frac{-\beta R_c}{2r_\pi} = \frac{-g_m R_c}{2}$$

$$A_d = [-g_m R_c / 2]$$

Common mode gain (A_c):



KVL in input loop

$$V_c = I_b r_\pi + 2R_e [1 + \beta] I_b$$

$$\text{Output voltage } V_o = -\beta I_b \cdot R_c$$

$$A_c = \frac{V_{o1}}{V_c} = \frac{-\beta R_c \cdot I_b}{[2(1 + \beta)R_e + r_\pi] I_b}$$

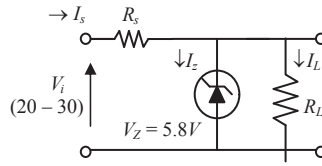
$$A_c = [-R_c / 2R_e] \text{ for } \beta \gg 1; r_\pi \ll 2R_e$$

Decreases A_c with $R_e \uparrow$

$$\text{CMRR} = [A_d / A_c]$$

$$\text{CMRR} = g_m R_e$$

52.



$$I_s = I_L + I_z$$

$$I_L = I_s - I_z$$

For design consideration

Load current is maximum when diode is just operate in break down region, As V_{in} increases, the load current remain but zener current increase.

For the zener diode to be operated in the breakdown region, the maximum load current is

$$I_L = I_s - I_z$$

$$i_{L(\max)} = \frac{V_{s(\max)} - V_z}{R_s} - I_{z(\min)}$$

$$= \frac{30 - 5.8}{1K} - [1/2] \text{ mA}$$

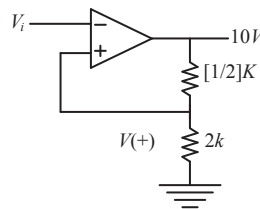
$$i_{L(\max)} = 23.7 \text{ mA}$$

53. Due to positive feed back circuit is always in saturation

$$V_{out} = \pm 10V; \text{ as } V_{supply} = \pm 10V$$

When $V_o = 10V$

Diode D_1 – open circuit, D_2 – Conduct

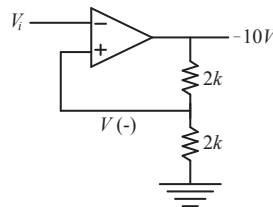


$$V_+ = \frac{2K}{[2 + (1/2)]K} \times 10$$

$$V_+ = 8V = V_i$$

When $V_o = -10V$,

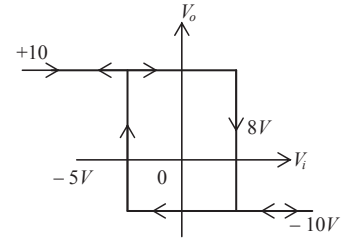
Diode $D_1 \rightarrow$ Conduct, $D_2 \rightarrow$ open circuit



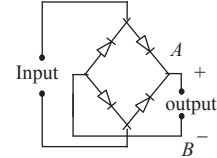
$$V_- = [2k/4k] \times (-10)$$

$$V_- = -5V = V_i$$

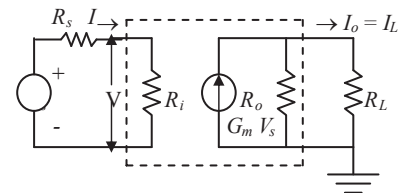
Hysteresis loop is



54. Full wave rectifier: In all case of supply only two diode conduct and gives terminal $A + Ve$ and terminal $B - Ve$



55. The voltage-current convertor or trans-conductance Amplifier is a Voltage controlled current source

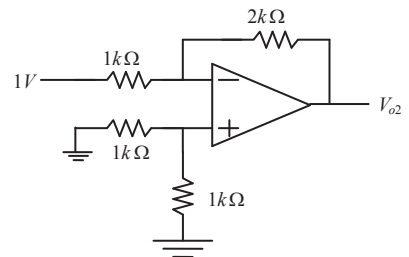


Transductions amplifier has voltage source at input end and current source at output end. Thus input resistance must be high and output resistance must be low.

$$|R_i| \gg R_s \text{ and } R_L \ll R_o$$

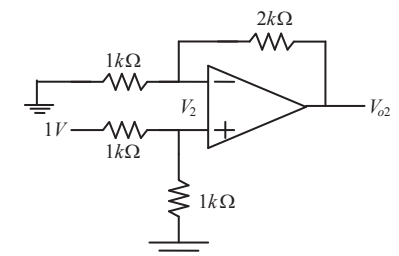
$$I_o = G_m V_s$$

56. For $-Ve$ terminal



$$V_{o1} = -\frac{2}{1}(1) = -2V \quad (1)$$

For $+Ve$ terminal



$$V_2 = \frac{1}{1+1} = \frac{1}{2} V; V_2 = \frac{1k(V_{o2})}{1k+2k}$$

$$\frac{1}{2} = \frac{1}{3} V_{o2}; V_{o2} = \frac{3}{2} V$$

or $V_{o2} = \left(1 + \frac{2}{1}\right) V_2 = 3 \times \frac{1}{2} = \frac{3}{2} V$

$$V_o = V_{o1} + V_{o2}$$

$$= -2 + \frac{3}{2} = -\frac{1}{2} = -0.5 V$$

Second Method

KCL at Node G,

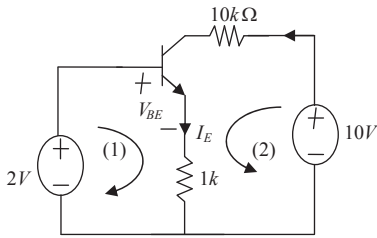
$$V_G = 0.5 V$$

$$\left(\frac{0.5-1}{1}\right) = \frac{(V_o-0.5)}{2}$$

$$-1 = V_o - 0.5$$

$$V_o = -0.5$$

57.

**First Method**

$V_{BE} = 0.7 V$; If we assume β is very large

KVL in base emitter loop

$$2 - V_{BE} = I_E R_E$$

$$1.3 = 1000 I_E$$

$$I_C \cong I_E \quad (\beta \text{ very large})$$

$$\therefore I_C \cong 1.3 \text{ mA}$$

KVL in collector emitter loop

$$V_{CC} = I_C (R_C + R_E) + V_{CE}$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

$$V_{CB} + V_{BE} = 10 - 1.3 \times 10^{-3} \times 11 \times 10^3$$

$$V_{CB} = -4.6 V - V_{BE} = -4.6 - 0.7 = -5.3$$

Collector junction is reverse bias and emitter junction is already forward bias as $V_{BE} = 2 V$ applied.

Therefore, BJT is in Saturation

Second Method

Assuming transistor in saturation

$$i_C = \frac{(10-0.2)}{(10+1)} \text{ mA}$$

$$= \frac{9.8}{11} \text{ mA} = 0.8909$$

Since β is very high thus I_B will be very small

For Base emitter loop

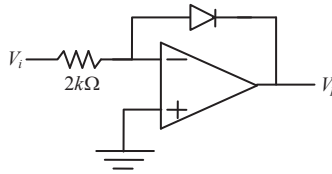
$$I_E = \frac{(2-0.7)}{1 K} = 1.3 \text{ mA}$$

$$I_E = I_B' + I_C$$

$$I_B' = 1.3 - 0.89 = 0.41$$

Thus $I_B' > I_B$ which shows transistor in saturation

58.



$$V_o = V_{o1} \text{ for } V_i = 2 V$$

$$V_o = V_{o2} \text{ for } V_i = 4 V$$

Relation between V_{o1} and V_{o2} is?

$\Rightarrow$ For algorithmic Amplifier

$$V_o = -V_T \ln \left(\frac{V_i}{R_o I_o} \right)$$

$$\therefore V_{o1} = -V_T \ln \left(\frac{2}{R_o I_o} \right)$$

$$= -V_T (\ln 2 - \ln R_o I_o)$$

$$V_{o2} = -V_T \ln \left(\frac{4}{R_o I_o} \right)$$

$$= -V_T (\ln 4 - \ln R_o I_o)$$

$$= -V_T (2 \ln 2 - \ln R_o I_o)$$

$$\therefore V_{o1} - V_{o2} = V_T \ln 2$$

Second Method

$$V_{o1} - V_{o2} = V_T \ln \left(\frac{V_{2I}}{V_{1I}} \right)$$

$$= V_T \ln \left(\frac{4}{2} \right)$$

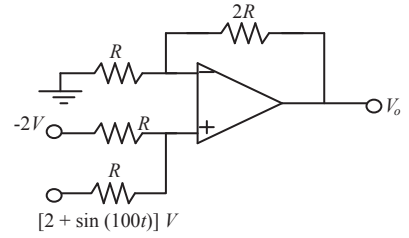
$$= V_T \ln (2)$$

$$V_{r1} = \frac{10-7}{200} \times 10 = 0.15$$

$$V_{r2} = \frac{16-7}{200} \times 10 = 0.45$$

59. If the NPN transistor base is connected to positive 10 V then transistor operate in active or saturation region $V_{CEsat} \cong 0$. If base register is open circuit the NPN transistor is in OFF condition whole of the V_{CC} is available to collector then collector to ground is +20 V

60.



$$V_o = -2 \left[1 + \frac{2R}{R} \right] \left[\frac{R}{2R} \right] + (2 + \sin 100 t)$$

$$\left(1 + \frac{2R}{R} \right) \left(\frac{R}{2R} \right)$$

$$= -3 + 3 + \frac{3}{2} \sin 100 t$$

$$= \frac{3}{2} \sin 100 t$$

61. When switch S_1 is open

$$\frac{V_o}{V_i} = A_v = -\frac{2R}{R} = -2 = x$$

When switch S_1 is closed, $A'_v = -[R/R]$
 $= -1 = [x/2]$

62. Since it is an ideal ops amplifier, it has infinite input resistance

$$V_o = -10^{-3} \times 10^3 = -1 V$$

63. Feedback factor = $\frac{10}{10+90} = \frac{10}{100} = \frac{1}{10}$

64. $R_E = 1 \text{ k}\Omega$,

KVL in base loop

$$V_{BE} + R_E I_E - 10 = 0$$

$$I_E = \frac{-0.7 - (-10)}{1 \times 10^3} = 9.3 \text{ mA}$$

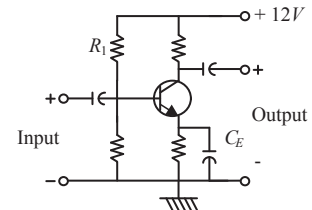
$$I_e = I_b + I_c = I_b + \beta I_b$$

$$I_c = (\beta + 1) I_b$$

$$\therefore 9.3 = 51 I_b$$

$$\therefore I_b = 18.2 \mu A$$

65.



With C_E

$$\text{Voltage gain, } A_v = \frac{-h_{fe} R_L}{h_{ie} + (1 + h_{fe}) R_E} \text{ If } R_E$$

by passed with capacitor C_E ,

A_v will increase.

Hence, after removing C_E mid band voltage gain decreases.

68.

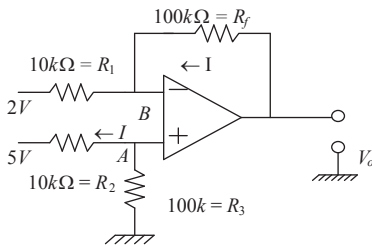
A	B	Output (Y)
0	0	0
0	1	0
1	0	0
1	1	1

↓

$Y = A \cdot B \rightarrow \text{AND Gate}$

69. Since it is inverting amplifier, therefore input impedance $R_i \cong R_1 \cong 1 \text{ k}\Omega$

70.



$$V_A = \frac{100 \text{ k}}{(100+10) \text{ k}} \times 5 = \frac{500}{110}$$

$$= \frac{50}{11} \text{ V} = V_B$$

$$I = \frac{\frac{50}{11} - 2}{10 \text{ k}} = \frac{50 - 22}{110 \text{ k}} = \frac{28}{110 \text{ k}}$$

$$I = \frac{V_O - V_B}{100 \text{ k}} \Rightarrow V_O - V_B = I \times 100 \text{ k}$$

$$V_O = V_B + I \times 100 \text{ k}$$

$$= \frac{50}{11} + \frac{28}{110 \text{ k}} \times 100 \text{ k} = \frac{50}{11} + \frac{2800}{110}$$

$$= \frac{50 + 280}{11} = \frac{330}{11} = 30 \text{ V}$$

Another Method

Present case is of differential amplifier

$$\text{Where } \frac{R_f}{R_1} = \frac{R_3}{R_2}$$

Here $R_f = R_3 = 100 \text{ k}$

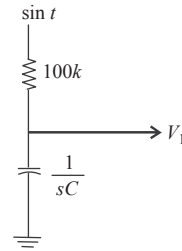
$$R_1 = R_2 = 10 \text{ k}$$

$$V_1 = 2 \text{ V}, V_2 = 5 \text{ V}$$

$$\text{Then output} = \frac{-R_f}{R_1} (V_1 - V_2)$$

$$= \frac{-100}{10} (2 - 5) = -10 \times -3 = 30 \text{ V}$$

71.



$$V_1 = \left(\frac{1/sC}{100 + \frac{1}{sC}} \right) \times \sin t$$

$$V_o = \left(1 + \frac{R_f}{R_1} \right) V_i = (1+1)V_f = 2V_i$$

$$= \frac{2 \sin t}{\left(100 + \frac{1}{sC} \right)}$$

$$= \frac{2 \sin t}{100 \text{ k} \times 10 \times 10^{-6} \text{ s} + 1}$$

$$= \frac{2 \sin t}{s + 1}$$

$$= \frac{2 \sin t}{\sqrt{2} \angle 45^\circ}$$

$$= \sqrt{2} \sin \left(t - \frac{\pi}{4} \right)$$

72. We know that gain of the op-amp is very high

$$V_i = Lt$$

So that Lt is restually short circuited

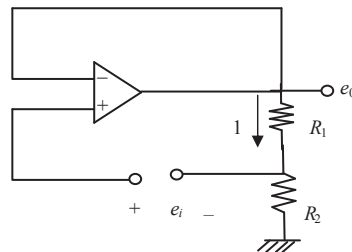
$$Z_{in} : R_1 + R_1 = 2R_1$$

73. $V_{o1} = 11 \text{ V}$

$$V_{o2} = -10 \text{ V}$$

$$V = V_{o1} + V_{o2} = 11 \text{ V} + (-10 \text{ V}) = 1 \text{ V}$$

74.



$$e_i = \frac{e_o \times R_2}{R_1 + R_2} \quad (1)$$

$$e_o - e_i = IR_1 \quad (2)$$

$$e_o - \frac{e_o R_2}{R_1 + R_2} = IR_1$$

$$e_o \left[1 - \frac{R_2}{R_1 + R_2} \right] = IR_1$$

$$e_o \left[\frac{R_1}{R_1 + R_2} \right] = IR_1$$

$$e_o = I(R_1 + R_2) \quad (3)$$

From (2) and (3)

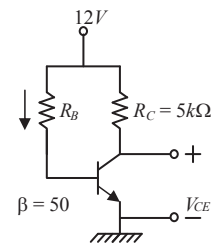
$$I(R_1 + R_2) - e_i = IR_1$$

$$e_i = IR_1 + IR_2 - I R_1$$

$$e_i = IR_2$$

$$I = \frac{e_i}{R_2}$$

75.



This diagram represent fixed biased

Apply KVL in CE loop

$$V_{CC} = I_C R_C + V_{CE}$$

$$V_{CE} = V_{CC} - I_C R_C$$

$$2 = 12 - I_C \times 5000$$

$$\therefore I_C = 2 \text{ mA}$$

KVL in $V_{CC} - B - E$ loop

$$V_{CC} = I_B R_B + V_{BE}$$

$$12 = I_B R_B + 0.7$$

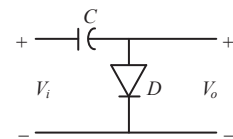
$$I_B = \frac{11.3}{R_B} = \frac{I_C}{\beta} = \frac{2 \text{ mA}}{50}$$

$$R_B = \frac{11.3 \times 50}{2 \times 10^{-3}} = \frac{11.3 \times 50}{2} \text{ k}\Omega$$

$$R_B = 283 \text{ k}\Omega$$

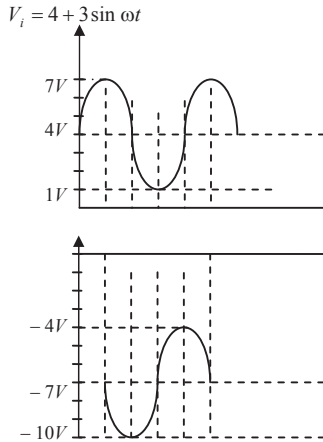
76. For 4 V input both diodes are $V_o = V_i$

77.



$$V_i = 4 + 3 \sin \omega t$$

Capacitor in this circuit acts as a DC restorer. It gets charged posture half cycle to +4 V.

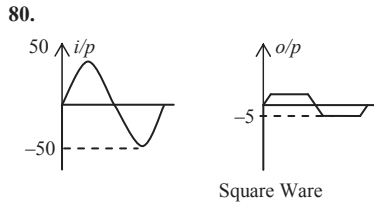


AC signal is using on $-7V$. Average of AC over one cycle = 0

∴ Resultant output = $-7V$

$$79. V_{oo} = V_{io} \times \left(1 + \frac{R_f}{R_i}\right)$$

$$= 10 \text{ mV} \times \left(1 + \frac{10}{1}\right) = 110$$



$$81. = V_{io} \left(1 + \frac{R_f}{R_i}\right)$$

$$= 11 \times 2 = 22 \text{ mV}$$

82. Using KVL at the inverting terminal, we have

$$\frac{V_i - 0}{R} = (0 - v_o) \text{ cS}$$

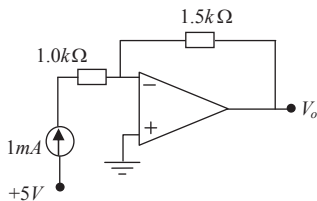
$$\text{or, } V_o = -\frac{1}{RC} \int V_i dt$$

The, given circuit behave as an integrator, therefore integration of square wave result that is triangles

83. Slew rate

$$= \frac{dv}{dt} = \frac{8}{T/2} = \frac{8}{0.2 \times 10^{-6}} = 40 \text{ V} / \mu\text{s}$$

84.



$$V_- = V_+ = 0 \text{ volt}$$

This is due to concept virtually grounded Ideal Ops amp $Z_{in} = \infty$, it has negligible current. Whole of the current flow through feedback register

$$\text{Then, } V_o = -1.5k \times 1 \text{ mV} = -1.5 \text{ volts}$$

85. Noise margin = $3V - 1V = 2V$

86. Light intensity = 10 mW/cm^2

$$\text{Active area} = 10^{-2} \text{ cm}^2$$

$$\text{Sensitivity} = 0.05 \text{ A/W}$$

$$= \frac{10 \times 10^{-3} \text{ W}}{\text{cm}^2} \times 10^{-2} \text{ cm}^2 \times \frac{0.05 \text{ A}}{\text{W}}$$

The photo-diode current

$$= 10 \times 10^{-3} \times 0.55 \times 10^2 \times 10^{-4}$$

$$= 0.55 \times 10^{-4} \text{ A}$$

$$\text{then, } V_o = -(100 \text{ K}\Omega) \times 0.55 \times 10^{-4} \text{ A}$$

$$= -5.5 \text{ volt}$$

87. For condition DC analysis is done

Apply KVL in CBE loop

$$24 - (I_C + I_B) 4.7 \text{ K} - I_B 560 \text{ K} - 0.7 = 0$$

$$\text{as } I_C = \beta I_B$$

$$\text{or } I_B = \frac{23.3}{560 \text{ K} + 101 \times 4.7 \text{ K}} = 0.0225$$

$$\text{then, } I_C = 2.3 \text{ mA}$$

88. For the gain of

Using KCL at the inverting terminal, we have

$$\frac{V_i - 0}{10 \text{ k}} = \frac{0 - V_o}{560 \text{ k}}$$

$$\text{or, } A_v = \frac{-V_o}{V_i} = 56$$

Gain of the inverting amplifier by formula is

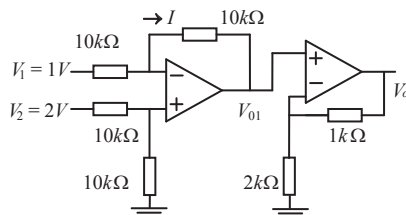
$$A_v = \frac{R_f}{R} = \frac{560}{10} = 56$$

$$\text{then, output offset voltage} = A_v \times v_{ios}$$

$$= -56 \times 5 \text{ mV}$$

$$V_{oos} = -280 \text{ mV}$$

89.



At Ops-amp

$$\text{Then } I = \frac{1-1}{10} = 0$$

Using voltage division

$$V = V_- = V_+ = 1 \text{ volt}$$

$$\therefore V_{01} = 1 \text{ V}$$

For Ops-amp, by voltage division

$$V_{01} = 1 = \frac{2}{3} V_{02}$$

$$V_{02} = \frac{3}{2} = 1.5 \text{ Volt}$$

$$\text{or, } V_o = 1.5 \text{ volts}$$

$$90. \text{ Time period, } T = 2RC \ln \frac{1+\beta}{1-\beta}$$

$$\text{Here, } \beta = \frac{1}{2}$$

$$\therefore T = 2RC \ln 3$$

$$= 2 \times 10^4 \times 10^{-6} \ln 3$$

$$= 0.0219 \text{ sec}$$

The circuit behaves as square wave generator.

91. Slew rate limit indicates how far the output voltage can change with time. As a large signal parameter, it defines the maximum rate at which the output can change from its most positive to its most negative values.

$$\text{Slew rate} = 100 \text{ V}/\mu\text{s};$$

$$\text{frequency} = 10 \text{ MHz}$$

In a cycle, the voltage varies by 10 V p to p

For a sine wave output, the voltage will be 5 V .

$$92. \text{ Given } A_{db} = 10 \log [P_o/P_i] = 60$$

$$\therefore [P_o/P_i] = 10^6$$

$$\therefore P_o = (10)^6 \times 2 \times 10^{-6} = 2 \text{ W.}$$

93. For CE with emitter resistance configuration the input resistance of the circuit, is given by

$$Z_{in} = h_{ie} + (1 + h_{fe}) R_e$$

This does not depend on R_L .

94. For CB configuration

$$h_{ib} = \frac{h_{ie}}{1 + h_{fe}} = \frac{5 \times 10^3}{100 + 1} = \frac{5000}{101} = 49.5 \Omega.$$

95. Frequency for undistorted output is 100 kHz , 10 V peak to peak

$$\text{Slew rate} = \frac{10}{100 \times 100} = 10$$

Hence, for 5 volt peak to peak input, the maximum frequency will be more than 100 kHz .

$$98. \text{ CMMR}(\text{db}) = 20 \log \frac{A_{DM}}{A_{CM}} = 80$$

$$\text{Or } \log \frac{A_{DM}}{A_{CM}} = 4$$

$$\text{Or } \frac{A_{DM}}{A_{CM}} = 10^4$$

$$\therefore A_{CM} = \frac{2 \times 10^4}{10^4} = 2.$$

$$104. I_C = \frac{I_{CBO}}{1-\alpha} + \frac{I_E}{1-\alpha}$$

For cut-off, $I_B = 0$

$$I_C = I_E = \frac{I_{CBO}}{1-\alpha} = I_{CEO}.$$

$$105. I_{DS} = I_{DSS} [1 - (V_{GS}/V_P)]^2 \text{ i.e., at } V_{GS} = 0, I_{DS} \text{ is maximum possible.}$$

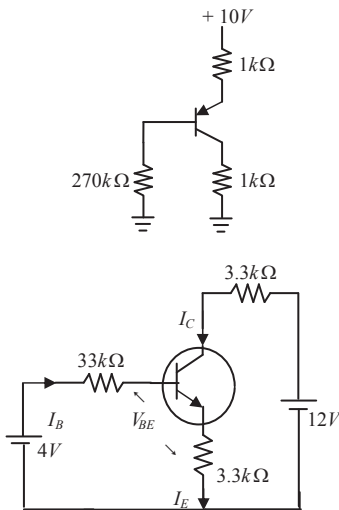
$$107. \text{ Apply KVL in } B-E \text{ loop, we get} \\ -4 + 33I_B + V_{BE} + 3.3I_E = 0 \\ [\because I_E = (1 + \beta) I_B]$$

$$\text{or } I_B = \frac{3.3}{33 + 3.3(\beta + 1)}$$

$$\text{or } I_B = \frac{3.3}{33 + 330} \text{ mA}$$

$$\text{and } I_C = \beta I_B = \frac{99(3.3)}{33 + 330} \text{ mA}$$

$$\text{or } I_C \approx \frac{3.3}{3.3 + 0.33} \text{ mA}$$



108. From the given circuit, we get

$$V_+ = \frac{1/j\omega C}{R + 1/j\omega C} \times V_{in} = \frac{V_{in}}{1 + j\omega RC}$$

For Ideal Op-amp $V_- = V_+$

KCL at V_- node

$$\text{and, } \frac{V_{in} - V_-}{R_1} = \frac{V_- - V_o}{R_1}$$

$$\text{or } V_o = 2V_- - V_{in} = 2V_+ - V_{in}$$

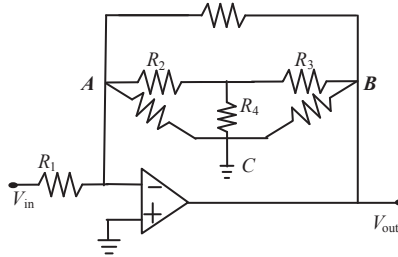
$$= \left[\frac{2}{1 + j\omega RC} - 1 \right] V_{in} = \frac{1 - j\omega RC}{1 + j\omega RC} V_{in}$$

$$\text{Then, } \angle(V_o/V_i) = -2 \tan^{-1} \omega RC$$

For $-90^\circ \leq \theta \leq 90^\circ$, Phase-shift

$$\angle(V_o/V_i) = \pm 180^\circ$$

109.



$$R_4 = 1 \text{ k}\Omega$$

$$R_2 = 10 \text{ k}\Omega$$

$$R_3 = 10 \text{ k}\Omega$$

$$\frac{V_{out}}{V_{in}} = - \left[\frac{R_2 + R_3 + \frac{R_2 R_3}{R_4}}{R_1} \right] \\ = - \frac{10 \times 10^3 + 10 \times 10^3 + \frac{10 \times 10^3 \times 10 \times 10^3}{10^3}}{10^3} \\ = - \frac{20 \times 10^3 + 100 \times 10^3}{10^3} = -120$$

Second Method

$$R_{AB} = \frac{R_2 R_3 + R_3 R_4 + R_4 R_1}{R_4} \\ = \frac{1 \times 10 + 10 \times 10 + 10 \times 1}{1} \\ = 120 \text{ k}$$

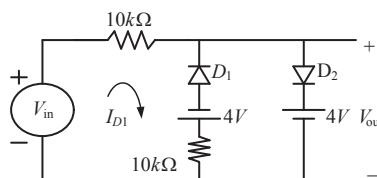
$$R_{AC} = \frac{120 \text{ k}}{10} = 12 \text{ k}$$

$$R_{BC} = \frac{120}{10} = 12 \text{ k}$$

$$\frac{V_o}{V_i} = \frac{-120}{1} = -120$$

110. Positive swing + 4 V

$$\text{Negative swing is } -4 + -6 \times \frac{10}{20} = -7 \text{ V}$$



For positive cycle D_2 ON, D_1 OFF then $V_{out} = 4 \text{ V}$

For negative cycle D_1 ON then D_2 OFF,

$$I_{D1} = \frac{V_{in} + 4}{20} = \frac{-10 + 4}{20} = \frac{-3}{10} \text{ mA}$$

Then $V_o = I_{D1} R = (10 \text{ k}) \times \frac{-3}{10} = -3 \text{ V}$

111. Mark period, $T_1 = 0.693 C (R_A + R_B) = 0.7 C (R_A + R_B)$

Space period, $T_2 = 0.693 C R_B = 0.7 C R_B$

$$\text{Period } T = T_1 + T_2 = 0.693 C (R_A + 2R_B) \\ = 0.7 C (R_A + 2R_B)$$

$$\text{Duty cycle, } \alpha = \frac{T_{ON}}{T} = 0.75, T = \frac{1}{f} = 10^{-4}$$

$$\text{or } T_{ON} = \alpha T = 0.75 T = 0.75 \times 10^{-4} = 75 \mu \text{ sec;}$$

$$T_{OFF} = 0.257 = 25 \mu \text{ sec.}$$

$$\text{As } T_{ON} = 0.7 C (R_A + R_B)$$

$$\text{or } \frac{75 \times 10^{-6}}{0.7 \times 10^{-8}} = R_A + R_B$$

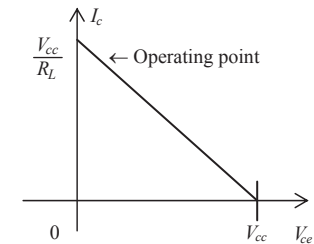
$$\text{or } R_A + R_B = 10.714 \text{ k}\Omega$$

$$\text{And } T_{OFF} = 0.7 C R_B$$

$$\text{or } R_B = \frac{25 \times 10^{-6}}{0.7 \times 10^{-8}} = 3.57 \text{ k}\Omega$$

$$\text{Thus } R_A = 7.25 \text{ k}\Omega$$

112.



$$V_{cc} = I_c R_c + V_{ce}$$

$$40 = \beta I_b R_c + V_{ce}$$

$$V_{ce} = 40 - 10 \times 0.5 \times 10 = 40 - 50 = -10$$

Since for $I_c = 5 \text{ mA}$, V_{ce} goes negative, then we take operating point as $(0V, 4A)$ i.e., at the I_c -axis.

113. For zener diode, Dynamic resistance

$$R_z = \frac{\Delta V_z}{\Delta I_z}$$

$$0.1 \text{ k}\Omega = \frac{V_L - V_z}{\Delta I_z} = \frac{3.5 - 3.3}{\Delta I_z}$$

$$\Delta I_z = \frac{0.2}{0.1 \text{ k}} = 2 \text{ mA}$$

114. The given diagram represent the current mirror case in which both the collector current are same. Therefore,

$$I = \frac{5 - 0.7}{1k} = 4.3 \text{ mA}$$

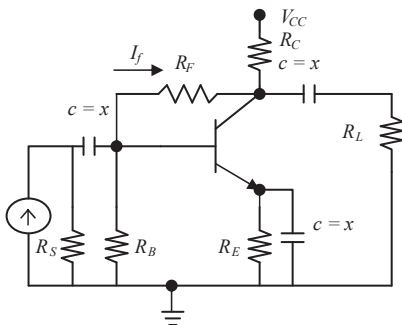
Given circuit is current mirror case i.e., transistor is same and β is very high in which both the collector current is same.

Current flowing across $1 \text{ k}\Omega$ is equal to I
Taking KVL

$$I_C \times 1 \times 10^3 + 0.7 - 5 = 0$$

$$I_C = \frac{5 - 0.7}{1 \times 10^3} = 4.3 \text{ mA}$$

115.



Since $V_o \gg V_i$

$$I_f = \frac{V_i - V_o}{R_F} = \frac{-V_o}{R_F} = KV_o$$

$$\text{Where } K = -\frac{1}{R_b}$$

Since feed back current is proportional to output voltage. Therefore this is *voltage shunt feed back*. If voltage is used as feed back then series case and current is used as feed back then shunt case. Hence present case is shunt feed back.

116. The peak reverse voltage in full-wave rectifier is $2V_m$, here V_m is the ac input peak value.

$$V_m = 50\sqrt{2} \text{ V}$$

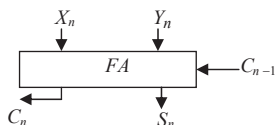
$$\text{Peak reverse voltage} = 100 \sqrt{2}.$$

117. From the circuit, it can be inferred that D_1 is OFF and D_2 is ON. Then, current through it would be 0 mA .

CHAPTER 8

LEVEL 1

1.



7. Decoding error is due to the propagation delay of FFs. To overcome these errors we employ a strobe input.

8. The 8085 Flags

The following flags are set or reset after the execution of an arithmetic or logic operation: data copy instruction do not affect any flags. i.e., Z–Zero, CY– Carry, – Sign., P–Parity, AC–Auxiliary Carry.

AC–Auxiliary Carry: In an arithmetic operation, when a carry is generated by digit D_3 and passed to digit D_4 , the AC flag is set. This flag is used internally for BCD (binary-coded decimal) operations: there is no jump instruction associated with this flag.

Branch Instructions change the program sequence.

9. Relaxation oscillator produces ramp output i.e., not sinusoidal.

$$10. f = A \oplus B = \overline{A}B + A\overline{B}$$

If Input is given to one input line and logic one to the other line
 $f = A.0 + \overline{A}.1 = \overline{A}$.

11. ASCII provides for parity check.

Basic ASCII is 7 bit code with parity bit it is 8 bit code.

12. In the Moore sequential model, the output is a function of the present state only.

13. The propagation delay time is the time interval between the trigger edge and the stabilization of the output to a new state.

There is minimum time, set up time, for which the data input be maintained at a constant value prior to the occurrence of the clock transition.

Similarly, there is a minimum time, called the hold time, for which the data input must not change after the application of the positive transition of the clock.

16. Carry output from first adder is given to carry-in of the next adder. This is known as **ripple carry**. Since the evaluation of FA depends on carry out from the previous FA, So it is slow.

For speeding up the carry generation process technique known as **Look-ahead Carry** is used. In look-ahead carry technique, the carry bits are generated before the actual summing operation takes place.

17. For a half – adder,

$$\text{Sum } S_1 = x_i \oplus y_i,$$

$$\text{Carry } C_i = x_i y_i$$

for a half-subtractor

$$\text{Difference } D_i = x_i \oplus y_i$$

$$\text{next borrow, } B_i = \overline{x_i} y_i.$$

18. Gray code

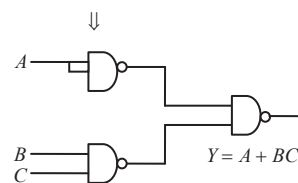
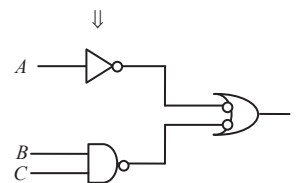
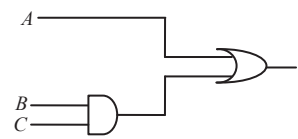
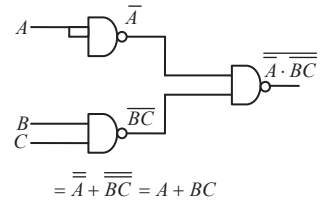
In this code, a decimal number is represented in binary form in such a way that each gray-code number differs from the preceding and the succeeding number by a single bit.

1. It has reflection properties
2. Un weighted code
3. Unit distance code
4. More error free code, used for input/output devices.

20. AND – OR $\rightarrow$ Realize by NAND

OR – AND $\rightarrow$ Realize by NOR

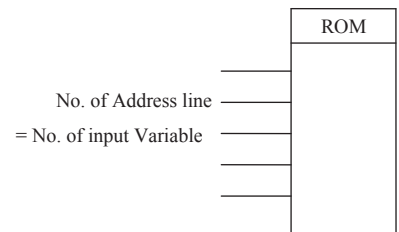
$Y = A + BC \rightarrow$ Realization by NAND



22. $A \rightarrow 1000001 = 65$

$$a \rightarrow 1100001 = 97.$$

23.



24. There are only two types of DAC i.e.,

1. Binary weighted resistor type DAC
2. R-2R ladder type DAC

Note that successive approximation type is an ADC.

25. Minimum number of gates equal to six is incorrect.

Other two options are correct.

26. A Flip-flop works as a frequency divider also.

$$1 \text{ ms} \rightarrow 1 \text{ kHz}, = 1000 \text{ Hz}$$

$$10 \text{ ms} \rightarrow 100 \text{ Hz}$$

Input 1000 Hz, output 100 Hz i.e., divided by 10.

33. In negative logic systems

One level is 0 and other is -ve voltage.

34. $Y = F(A, B) = M(0, 1, 2, 3)$.

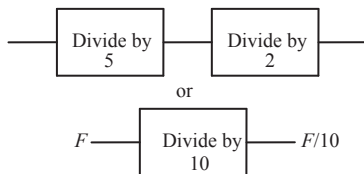
	A	0	1
B	0	X	X
	1	X	X

= 1

∴ Output is independent of input

35. 1. ECL is fastest ∴ least propagation delay
2. CMOS has largest fan out
3. CMOS has biggest Noise Margin (45% of V_{DD})
4. CMOS has lest power dissipation.
37. Loader takes object program from secondary memory to main memory i.e., it takes object file, form assembler and give exe files.
38. To obtain $10 \mu\text{s}$ form $100 \mu\text{s}$ square wave, we have to divide $100 \mu\text{s}$ by 10. Hence divide by 10 counter is required.

Divide by 10 = Divide by 5 circuit followed by divide by 2



$$\therefore \text{Time} = \frac{1}{F} \text{ will be } \frac{10}{F}$$

$$\therefore 10 \mu\text{s} \text{ will becomes } 100 \mu\text{s}.$$

39. To increase the pulses width we need pulse stretcher circuit i.e., mono-stable multi-vibrator By using monostable multivibrator (by choosing value of R and C) we can convert $1 \mu\text{s}$ to 1ms pulse
41. The program counter is an operational register which always holds the address of either the next instructions to be executed or the address of the next word of a multiword instruction that has not been completely fetched

- 43.

Truth Table

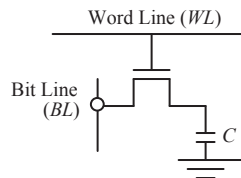
$$\text{NOR} = \overline{A + B}$$

Input		A + B	$\overline{A + B}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

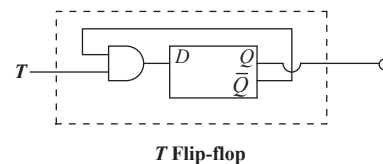
$$\text{EX-NOR} = A \odot B$$

Input		$A \oplus B$	$A \odot B$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	0	1

- 45.



- 46.



In a switch ring counter using D-FF, the complementary output $\bar{Q}$ is connected to D input. For single input it becomes T-FF

49. Since the delay has to be finite number of clock
50. Totem-pole transistor Q_4 is used because they produce low output impedance which act as power driver or power buffer.

53. The output resistance of Darlington pair is low and hence RC time constant is reduced, speeding up the operation.

54. With modification, V_{CC} and V_R (i.e. two ground) and connections are made one for the emitter follow and one for the current switch and voltage reference.

The reason for the separate connections is to isolate the switching transients (large current and voltage spikes caused by charging and discharging the external load and parasitic output capacitance)

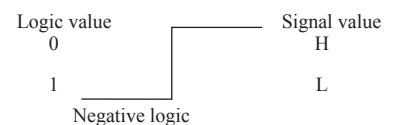
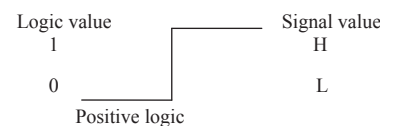
That appear at the output of the emitter follower from affecting the differential pair and reference circuits (the internal stages)

Since ECL gates have low noise margin (0.3V) this configuration helps to suppress the noise levels i.e., eliminate the effect of power line glitches on the biasing circuit.

55. Change in output occurs when the state of the slave is affected.
56. Dual slope A/D is
1. Very slow
 2. Highly accurate
 3. Capable of eliminating hum noise
57. Digital families should have noise immunity
58. A sample and Hold is normally required before successive approximation analog to digital converter as it is most use full if multiplexing is required
62. Multiplexer can be used as parallel to series converter.
63. A mod-K ring counter require K FF.
64. K-map produces a circuit diagram with a minimum number of gates and of the minimum number of inputs to the gate.
- The number of input terminals is referred to as the fan-in
65. For CE configuration, the input switching signal (current or voltage) required is low in comparison with the current or voltage being switched or controlled.

$$\begin{aligned}
 67. \quad V_o &= \frac{V}{2} + \frac{V}{4} + \frac{V}{8} + \frac{V}{16} + \frac{V}{32} + \dots \frac{V}{2^n} \\
 &= \frac{V}{2} \times 1 + \frac{V}{4} \times 1 + \frac{V}{8} \times 0 + \frac{V}{16} \times 1 + \frac{V}{32} \times 1 \\
 &\quad + \frac{V}{64} \times 0 + \frac{V}{128} \times 1 + \frac{V}{256} \times 1 \\
 &= V \left[\frac{1}{2} + \frac{1}{4} + \frac{1}{16} + \frac{1}{32} + \frac{1}{128} + \frac{1}{256} \right] \\
 &= \frac{V}{256} [128 + 64 + 16 + 8 + 2 + 1] \\
 &= \frac{20}{256} [218] = 17.1.
 \end{aligned}$$

- 68.



69.

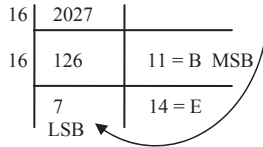
		AND	OR	NAND	NOR
A	B	AB	A+B	$\overline{AB}$	$\overline{A+B}$
0	0	0	0	1	1
0	1	0	1	1	0
1	0	0	1	1	0
1	1	1	1	0	0

70. F's complement means 16's. Complement. For present case

$$2BFD \rightarrow \begin{array}{r} 2 \quad 11 \quad 16 \quad 24 \\ -16 \quad 16 \quad 16 \quad 16 \\ \hline 14 \quad 4 \quad 0 \quad 2 \end{array} \rightarrow (D402)_F$$

71. $3 \times 512 + 7 \times 64 + 54 \times 8 + 3$

$$= 1536 + 448 + 40 + 3 \\ = -(2 \ 0 \ 2 \ 7)_{10} = (B \ E \ 7)_{16} \\ = (1011 \ 1110 \ 0111)_2$$



$$(2 \ 0 \ 2 \ 7)_{10} = (B \ E \ 7)_{16} \\ = (1011 \ 1110 \ 0111)_2$$

LEVEL 2

1. $Y = \overline{A \overline{B} + \overline{B} \overline{C} + \overline{C} \overline{A}}$

$$Y = (\overline{A \overline{B}})(\overline{\overline{B} \overline{C}})(\overline{\overline{C} \overline{A}})$$

$$Y = (\overline{A + B})(\overline{\overline{B} + \overline{C}})(\overline{\overline{C} + \overline{A}}) \\ = (A + B)(B + C)(C + A)$$

2. LHS: $(A \overline{A} + AC + \overline{A}B + BC)(B + C)$
 $= ABC + \overline{A}B \cdot B + B \cdot BC + ACC + \overline{A}BC + BCC$
 $= ABC + \overline{A}B + BC + AC + \overline{A}BC + BC$
 $= BC + \overline{A}B + BC + AC$
 $\overline{A}B + BC + AC$

RHS: $(A + B)(\overline{A} + C)$
 $= A\overline{A} + AC + \overline{A}B + BC$
 $AC + \overline{A}B + BC$

3. It is an oscillating circuit and its output is a square wave with the time period T

$$T = 6 \Delta t$$

where, Δt = propagation delay time of inverter

4. Flash/simultaneous/Parallel ADC is same, For this type ADC

$$\text{Number of comparators} = 2^n - 1 = 2^3 - 1 = 7$$

where, n = number of bits.

6. T flip-flop change its output when ever input is high i.e.

Truth table of T-Flip flop as follows.

T	Q_n	Q_{n+1}
0	0	0
0	1	1
1	0	1
1	1	0

Characteristic equation

$$Q_{n+1} = \overline{T} Q_n + T \overline{Q}_n$$

8. $V_o = \frac{V}{2} + \frac{V}{4} + \frac{V}{8} + \frac{V}{16} + \frac{V}{32} + \dots + \frac{V}{2^n}$
 $= \frac{V}{2} \times 1 + \frac{V}{4} \times 1 + \frac{V}{8} \times 0 + \frac{V}{16} \times 1 + \frac{V}{32} \times 0$
 $= V \left[\frac{1}{2} + \frac{1}{4} + \frac{1}{16} \right] = \frac{V [8 + 4 + 1]}{16} = \frac{10}{16} \times 3$
 $= \frac{130}{16} = 8.125 \text{ V.}$

9. $X = ABCD + A\overline{B}CD + \overline{A}BCD + \overline{A}\overline{B}CD$
 $= ACD(B + \overline{B}) + \overline{A}CD(B + \overline{B})$
 $= ACD + \overline{A}CD = CD(A + \overline{A}) = CD$

Another Method

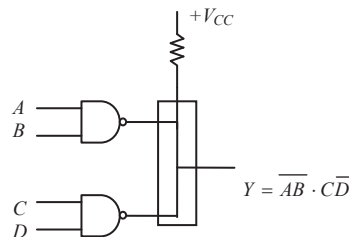
According to Redundancy theorem in a Boolean expression in SOP form, if the same factor is present in more than one term, the other terms are redundant.

12. Since its MSB is 1, therefore, the number is negative.

$$2\text{'s complement of } 1100 = 1100 + 1 = 1101 = +13$$

therefore, $(10011) = (-13)_{10}$ 2's complement.

13.



Output of some gates connected to common pull up resistor is released as AND function.

15. This positive number therefore single bit is zero. Binary equivalent of 22 is 10110, and 0.5625 Binary equivalent is 0.1001

$$0.5625 \times 2 = 1.1250$$

$$0.125 \times 2 = 0.250$$

$$0.250 \times 2 = 0.500$$

$$0.500 \times 2 = 1.000.$$

16. Hexa substitution

	15	16
	↑	↑
2	0	0
	14	3
	↓	↓
	E	3

$$(200)_{16} - (11D)_{16}$$

$$= 16^2 \times 2 - 16^2 + 16 + 13$$

$$= 512 - 256 + 16 + 13$$

$$= 512 - 285 = 227$$

Second Method

$$(E \ 3)_{16}$$

$$14 \times 16 + 3$$

$$160 + 64 + 3 = 227.$$

17. Therefore $77_{16} - 3B_{16} = 3C_{16}$.

18. $(77)_{16} \rightarrow 0111 \ 0111$

$(3 \ B)_{16} \rightarrow 0111 \ 1011$

$0111 \ 1100 \rightarrow (3 \ C)_{16}$

Therefore, $(77)_{16} - 3B_{16} = 3C_{16}$.

19. The output of ADC depends on temperature variation and given by

$$V_{e1} = V_{e2} \pm T_{coeff} (T_2 - T_1)$$

$$(V_{e2} - V_{e1})$$

$$V_{50} = V_{25} \pm T_{coeff} \Delta T$$

$$\Delta V = T_{coeff} \times \Delta T$$

$$\Delta V = \frac{1/2^{10}}{2} = \frac{1/10^3}{2}$$

$$\text{or, } \frac{10^{-3}}{2} = T_{coeff} \times (50 - 25) T_{coeff} \times 25$$

$$\frac{10^{-3}}{2 \times 25} = \frac{10^{-3}}{50 \times 2} \times 2 = \frac{2 \times 10^{-3}}{100} \\ = \frac{20 \times 10^{-3}}{10^3} = 20 \times 10^6 \text{ V/}^\circ\text{C}$$

$$T_{coeff} = 200 \mu\text{V/}^\circ\text{C.}$$

20. Draw excitation table and k-map

$$= J_n Q_n + \overline{K}_n Q_n; \quad Q_{n+1} = J \overline{Q}_n + \overline{K} Q_n$$

21. Johnson-counter is $2N$ counter

where N = Number of bits

Number of state $2 \times 4 = 8$ state (used)

Total number states $= 2^N = 16$

Remaining number states $= 16 - 8 = 8$ states.

22. NOR: $Y = \overline{A+B}$

EX-NOR: $Y = A \odot B = \overline{A \oplus B} = AB + \overline{A}\overline{B}$

23. $Z = (\overline{A+B})(\overline{A+C})(\overline{B+C})$
 $= (\overline{AA} + \overline{AC} + \overline{AB} + \overline{BC})(\overline{B+C})$
 $= (\overline{AB} + \overline{BC} + \overline{AC})(\overline{B+C})$
 $= \overline{AB}\overline{B} + \overline{AB}\overline{C} + \overline{BC}\overline{B} + \overline{BC}\overline{C} + \overline{AC}\overline{B} + \overline{AC}\overline{C}$
 $= \overline{AB}\overline{C} + \overline{B}\overline{C} + \overline{A}\overline{B}\overline{C} + \overline{A}\overline{C}$
 $= \overline{C}(\overline{AB} + \overline{B} + \overline{A}) + \overline{A}\overline{C}$
 $= \overline{A}\overline{C} + \overline{B}\overline{C} = (\overline{A+B})\overline{C}$

24. $= A + \overline{AB} + \overline{AC}$
 $= A$ (Redundancy theorem)
 Therefore, zero NAND gate.

25. $S = A \oplus B = \overline{AB} + \overline{AB}$
 $C = AB$

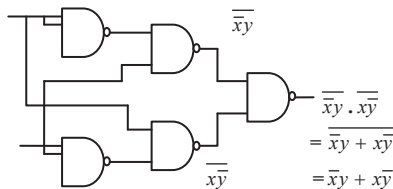
26. $D = A \oplus B = \overline{AB} + \overline{AB}$ $X = \overline{AB}$

27. BCD center thus 0-9 state
 Then $2^n \geq N$
 where N = number of state
 n = number of F.F required
 $2^n \geq 10 \Rightarrow n = 4$

28. $2^6 = 64$; $2^3 \times 9 \neq 64$

29. 15-bit for counting and 1-bit for preset
 i.e., $15 + 1 = 16$ bit.

30.



31. $f = A + \overline{AB} + \overline{AC}$
 $= A + \overline{AB}(1+C) = 1(1+\overline{B}) = A$

The given function output is A which is directly available from input, therefore no need to use NAND gates.

32. Let the AND-OR function is

$$F = x_1x_2 + x_3x_4$$

When all the gate replace by NOR

So, $F^P = \overline{(x_1 + x_2)} + \overline{(x_3 + x_4)}$
 $= \overline{(x_1 + x_2)} + \overline{(x_3 + x_4)}$
 $= (\overline{x_1} + \overline{x_2})(\overline{x_3} + \overline{x_4})$

33. Decimal to octal conversion

$$0.3125 \times 8 = 2.5$$

$$0.5 \times 8 = 4.0$$

$$(0.3125)_{10} \equiv (0.24)_8$$

34. Decimal Number presentation in power of 2

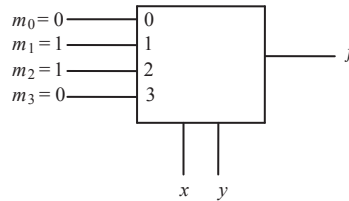
$$(4 \times 4096) + (9 \times 256) + (7 \times 16) + 5$$

$$= (2^2 \times 2^{12}) + (2^3 + 1) \times 2^8 [2^2 + 2^0 + 1 \times 2^4 + 2^2]$$

$$= 2^{14} + 2^{11} + 2^8 + 2^6 + 2^5 + 2^4 + 2^2 + 2^0$$

Therefore: number of 1's present is
 $= 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 = 8$

36.



$$f(xy) = (\overline{x}\overline{y})m_0 + (x\overline{y})m_1 + (\overline{x}y)m_2 + (xy)m_3$$

where, $m_0 = 0$;

$$m_1 = 1$$

$$m_2 = 1;$$

$$m_3 = 0$$

$$f(xy) = x\overline{y} + \overline{x}y = x \oplus y$$

37. Solving the Boolean expression, we get

$$f = (x+y)(\overline{x}+z)(y+z)$$

$$= (x\overline{x} + xz + \overline{x}y + yz)(y+z)$$

$$= xyz + xz + \overline{x}y + \overline{x}yz + yz = yz(x + \overline{x} + 1)$$

$$= yz + xz + \overline{x}y = (x+y)(\overline{x}+z)$$

38.

Table for Boolean IDENTITIES

1.	$0.A = 0$	$A+0 = A$
2.	$A.1 = A$	$A+1 = 1$
3.	$A.A = A$	$A+A = A$
4.	$A.A' = 0$	$A+A' = 1$

Duality is defined for hunting tone system just as it is for other axiomatic system and the dual of a give expression can be derive for simply replacing the “.” with “+” and “+” with “.” and 0's with 1's and 1's with 0's in the expression

$$(A+B).(\overline{A}+C) = AC + \overline{A}B$$

39. For base 4 numbers system two digit binary equivalent are used

$$(2.3)_4 + (1.2)_4 = (10.11)_2 + (01.10)_2$$

$$= (100.01)_2 = (10.1)_4$$

41. $(135)_x + (144)_x = (323)_x$

Let, base is x , then,

$$1 \times x^2 + 3x + 5 + 1 \times x^2 + 4x + 4 = 3x^2 + 2x + 3$$

$$\text{or, } 2x^2 + 7x + 9 = 3x^2 + 2x + 3$$

$$\text{or, } x^2 - 5x - 6 = 0$$

$$\text{or, } x^2 - 6x + x - 6 = 0$$

$$\text{or, } x(x-6) + 1(z-6) = 0$$

$$\text{or, } (x-6)(x+1) = 0$$

$$x = 6, x = -1$$

Radix cannot be negative therefore radix $x = 6$.

42. Cascaded network is series network MOD-N counter divide the clock frequency by N .

$$\text{Overall modulus} = 3 \times 4 \times 5 = 60$$

Therefore cascaded network modulus is multiplied. Finally lowest output frequency is divided by overall MOD to clock frequency.

Lowest output frequency

$$= \frac{12 \times 1000}{3 \times 4 \times 5} \text{ kHz} = 200 \text{ kHz}$$

44. $X(P, Q, R) = \pi(0, 5)$

$$\rightarrow POS = (P+Q+R)(\overline{P}+Q+\overline{R})$$

$$P \quad Q \quad R$$

$$0 \rightarrow 0 \quad 0 \quad 0 = (P+Q+R)$$

$$5 \rightarrow 1 \quad 0 \quad 1 = (\overline{P}+Q+\overline{R})$$

$$Y = PQ + P\overline{R} + Q\overline{P} + Q + Q\overline{R} + R\overline{P} + RQ$$

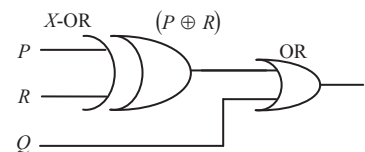
$$= PQ + QP + (P \oplus R) + Q(1+R)$$

$$= PQ + Q\overline{P} + (P \oplus R) + Q$$

$$= Q(1+P) + Q\overline{P} + (P \oplus R)$$

$$= Q + Q\overline{P} + (P \oplus R)$$

$$Y = Q + (P \oplus R)$$



$$= B(\overline{AC} + \overline{A}C)$$

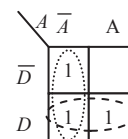
45.

$$F = AD + ABCD + ACD + AB + ACD + AB$$

$$= AD + ACD + \overline{A} + \overline{A}C\overline{D}B$$

$$= AD + \overline{A} + A\overline{C}D$$

$$= AD + \overline{A}$$



$$f = \overline{A} + D$$

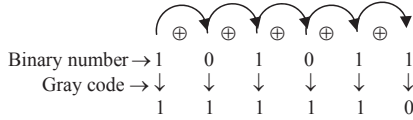
46. $(A+B)(A+\bar{B})$

$$= AA + A\bar{B} + AB + B\bar{B}$$

$$= A + A = A.$$

47. $A \otimes B \rightarrow \text{EX-OR} \rightarrow \bar{A}B + A\bar{B}.$

48. 111110.



49. $(BA)_{16} \rightarrow 11 \times 16 + 10 = 176 + 10 = 186$
 $(AB)_{16} \rightarrow 10 \times 16 + 11 = 160 + 11 = 171$
 $(BA)_{16} - (AB)_{16} = (186 - 171)_{10} = (15)_{10}$
 $= (F)_{16}$

50. $Q_{n+1} = J_n \bar{Q}_n + \bar{K}_n Q_n.$

Truth Table for JK

Inputs		Output
J_n	K_n	Q_{n+1}
0	0	Q_n
0	1	0
1	0	1
1	1	$\bar{Q}_n$

State Table for JK

Q_n	J_n	K_n	Q_{n+1}
0	0	0	0
	0	1	0
	1	0	1←
	1	1	1←
1	0	0	1←
	0	1	0
	1	0	1←
	1	1	0

$$Q_{n+1} = J_n \bar{Q}_n + \bar{K}_n Q_n.$$

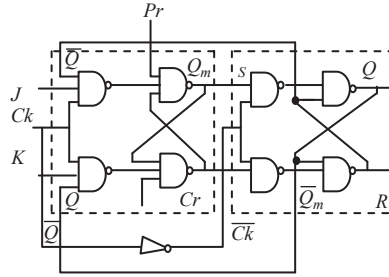
51. For de-multiplexer number of selector = $\log_2 n$

where, n = Number of input line for MUX or
 Number of output line for DEMUX.

52. The Master-Slave J-K flip-flop.

A master-slave J-K flip-flop is a cascade of two S-R flip-flops, with feedback from the output of the second to the inputs of the first.

Positive clock pulses are applied to the first flip-flop (master) and the clock pulses are inverted before these are applied to the second flip-flop, (slave) i.e., master is positive edge triggered and slave is negative edge triggered.



53. The correct match/answer is given below:

(Circuit)	(Application)
Ripple up counter	Transient states
Synchronous down Counter	To create delay
Shift left register	Multiplication
Shift right register	Division

54. % Resolution = $\frac{1}{2^n - 1} \times 100$

$$= \frac{1}{2^8 - 1} \times 100 = \frac{1}{256 - 1} \times 100$$

$$= \frac{1}{255} \times 100 = 0.004 \times 100 = 0.4\%.$$

55. For parallel comparator ADC

The number of comparator = $2^n - 1$
 where n = number of bits

In present case, Number of comparator = 1

$\therefore$ Number of bit = 1

i.e., as 1 bit quantize.

56. Resolution = $\frac{1}{2^n - 1} = \frac{1}{2^{10} - 1} = \frac{1}{1023}$

For 0 – 5V range maximum peak to peak ripple allowed

$$= \text{Maximum input} \times \text{Resolution}$$

$$= 5 \times \frac{1}{1023} = 5 \text{ mV}.$$

58. In Duality AND converted to OR & OR converted to AND i.e., $\rightarrow + \& + \rightarrow$.

$$AB + \bar{A}C = (A+C)(\bar{A}+B) \text{ Its Duality is}$$

$$(A+B)(\bar{A}+C) = AC + \bar{A}B$$

59. $45 = K \times (1010)_{10}$

$$= K \times 9$$

$$\text{Hence } K = 0.5$$

$$\text{Hence } V = 0.5 \times (1010)_{10} = 0.5 \times 6 = 3.0 \text{ V}.$$

61. $\frac{\text{Error}}{5} \times 100 = 0.2$

$$\text{Hence error} = \frac{1}{100} V = 100 \text{ mV}.$$

62.

Truth Table

A	B	C	Y
0	0	0	0
0	0	1	0
0	1	0	0
0	0	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

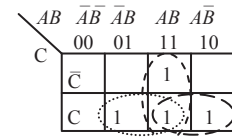
Then Boolean equation become

$$Y = ABC + A\bar{B}\bar{C} + \bar{A}B\bar{C} + A\bar{B}C$$

$$BC + AC + AB + ABC$$

$$BC + AC + AB(1+C)$$

$$BC + AC + AB.$$



63. TTL Parameters are

Maximum fan out = 12

$$V_{IH\min} = 2$$

$$I_{OL\max} = 16$$

Direct compatibility with CMOS is possible.

64. For 2^n states, n member elements are needed.

65. $25 \times 4 = 10ns$

66. Resolution of the ADC,

$$R = \left[\frac{V}{2^n} \right] = \frac{10}{10^{12}} = \frac{10}{10^{24} \times 4} = 2.44 \text{ mV}.$$

69. $+-*\uparrow ABCD / E / F + GH$

$$\Rightarrow A \uparrow B * C - D + E / F / G + H$$

Symbols are inserted in reverse order

$$= A^B * C - D + E / F / G + H.$$

70.

State Table

Q_n	S_n	R_n	Q_{n+1}
0	0	0	0
	0	1	0
	1	0	1←
	1	1	?

Q_n	S_n	R_n	Q_{n+1}
1	0	0	1←
	0	1	0
	1	0	1←
	1	1	?

$$Q_{n+1} = \bar{Q}_n S_n \bar{R}_n + Q_n \bar{S}_n \bar{R}_n + Q_n S_n \bar{R}_n$$

$\bar{S}_n \bar{R}_n$	$S_n \bar{R}_n$	$S_n R_n$	$\bar{S}_n R_n$
$\bar{Q}_n$			
Q_n			

$$Q_{n+1} = S_n \bar{R}_n + \bar{R}_n Q_n$$

Excitation Table for S-R

Q_n	Q_{n+1}	S_n	R_n
0	0	0	ϕ
0	1	1	0
1	0	0	1
1	1	ϕ	0

Where, ϕ = (don't care).

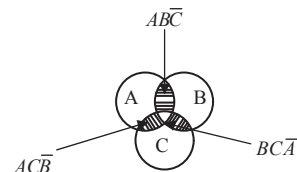
71. Access time

$$= 0.95 \times 10 + 0.05 \times 100 = 14.5 \text{ ns.}$$

74. $(A+B) \cdot (\bar{A}+C) \cdot (B+C)$

$$\begin{aligned} &= (A\bar{A} + \bar{A}B + AC + BC)(B+C) \\ &= (0 + \bar{A}B + AC + BC)(B+C) \\ &= \bar{A}BB + ABC + BBC + \bar{A}BC + ACC + BCC \\ &= \bar{A}B + ABC + BC + \bar{A}BC + AC + BC \\ &= \bar{A}B + BC(A + \bar{A}) + BC + AC \\ &= \bar{A}B + BC + AC \\ (A+B)(\bar{A}+C) &= \bar{A}B + BC + AC. \end{aligned}$$

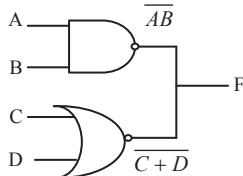
76.



$$AB\bar{C} + \bar{A}BC + A\bar{B}C$$

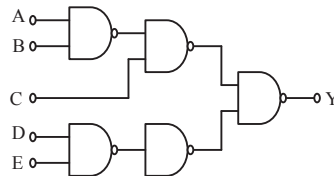
Because center portion is not shaded.

77.



$$\text{Then } F = \bar{A}\bar{B} + C + D.$$

78. $= \bar{A}\bar{B} \rightarrow \bar{A}\bar{B} \cdot C$



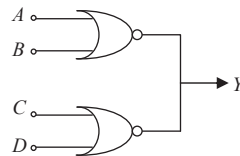
$$\bar{D}\bar{E} \rightarrow \bar{D}\bar{E} \rightarrow DE$$

$$Y = (\bar{A}\bar{B} \cdot C) \cdot DE$$

$$Y = (\bar{A}\bar{B} \cdot C) + \bar{D}\bar{E}$$

$$\begin{aligned} &= \bar{A}\bar{B} \cdot C + \bar{D}\bar{E} \\ &= (\bar{A} + \bar{B})C + \bar{D}\bar{E}. \end{aligned}$$

79.

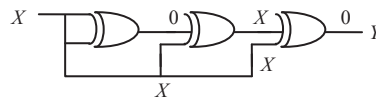


$$Y = \bar{A} + \bar{B} + \bar{C} + \bar{D}.$$

80.

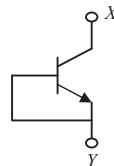
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

$$Y = X \oplus X = 0 \text{ always}$$



$$\therefore Y = 0.$$

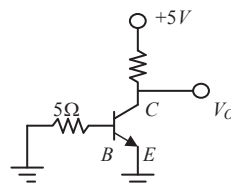
NPN transistor



$\therefore$ In this configuration transistor is in cutoff mode of operation.

81. Transistor is in cutoff state $\therefore$

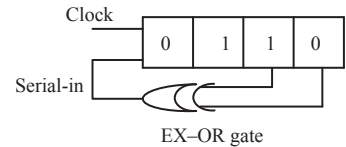
$$V_o = V_{cc} = 5 \text{ V.}$$



82. $F = \overline{A+B+C+D+E}$

$$\begin{aligned} &= \overline{A+B+C} \cdot \overline{D+E} \\ &= (\bar{A} + \bar{B} + \bar{C})(\bar{D} + \bar{E}) \\ &= (\bar{A} + \bar{B} + \bar{C})(\bar{D} \bar{E}). \end{aligned}$$

83.



Initial	0	1	1	0
1 st clock	0	1	1	0
2 nd clock	0	1	0	1
3 rd clock	1	0	1	0

84. For minimization of Boolean expression in present case minimum two variable should have same Boolean variable i.e.,

$$A\bar{B} + AB = A(\bar{B} + B) = A.$$

85. AND gate output $X = 1$ which needs its input must be

$$X = (A \oplus B) \cdot (B \odot C)$$

$$A \oplus B \text{ will be 1 when } A \neq B$$

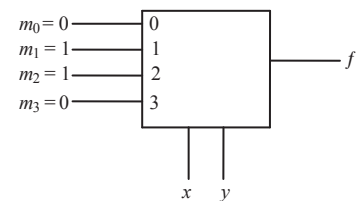
$$(B \odot C) \text{ will be 1 when } B = C;$$

$$A \neq B = C$$

So possible values are (0, 1, 1) and (1, 0, 0)

C must be 1 for 1 output of AND gate there for logic input is (0, 1, 1).

86.



$$f(xy) = (\bar{x}\bar{y})m_0 + (x\bar{y})m_1$$

$$+ (\bar{x}y)m_2 + (xy)m_3$$

$$\text{where, } m_0 = 0;$$

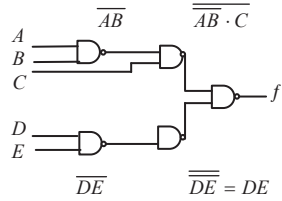
$$m_1 = 1$$

$$m_2 = 1;$$

$$m_3 = 0$$

$$f(xy) = x\bar{y} + \bar{x}y = x \oplus y.$$

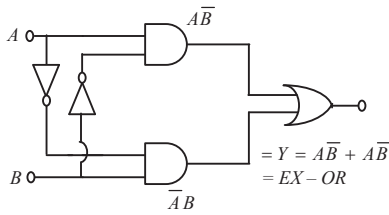
87.



$$f = \overline{\overline{A} \cdot \overline{B} \cdot \overline{C}} \cdot \overline{\overline{D} \cdot \overline{E}} = \overline{\overline{A} \cdot \overline{B} \cdot \overline{C}} \cdot \overline{\overline{D} \cdot \overline{E}}$$

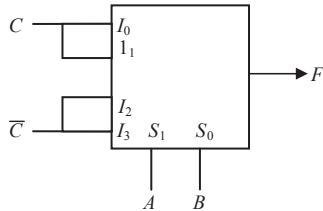
$$= \overline{\overline{A} \cdot \overline{B} \cdot \overline{C}} \cdot \overline{\overline{D} \cdot \overline{E}} = (\overline{\overline{A} \cdot \overline{B} \cdot \overline{C}}) \cdot \overline{\overline{D} \cdot \overline{E}}$$

89. EX-OR.



LEVEL 3

2.



	S_1	S_0	F
	A	B	
I_0	0	0	C
I_1	0	1	C
I_2	1	0	$\overline{C}$
I_3	1	1	$\overline{C}$

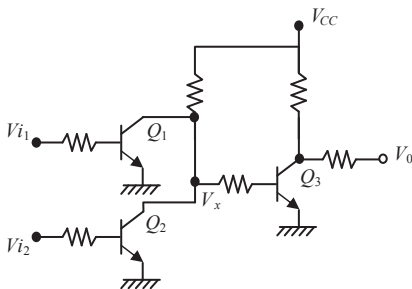
$$F = \overline{A} \overline{B} C + \overline{A} B C + A \overline{B} \overline{C} + A B \overline{C}$$

$$= \overline{A} C [\overline{B} + B] + A \overline{C} [\overline{B} + B]$$

$$= \overline{A} C + A \overline{C}$$

$$= A \oplus C$$

3.



V	Q_1	V_2	Q_2	V_x	Q_3	V_0
L	OFF	L	OFF	H	ON	L
L	OFF	H	ON	L	OFF	H
H	ON	L	OFF	L	OFF	H
H	ON	H	ON	L	OFF	H

The circuit represents an OR

5. A_0 and A_1 can take any value from 00 to 11
Chip select

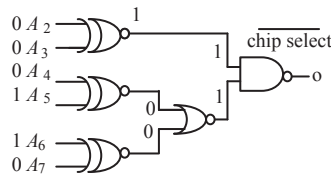
$= A_2 \overline{A_3} + \overline{A_2} A_3 + \overline{A_4} A_5 + A_4 \overline{A_5} + \overline{A_6} A_7 + A_6 \overline{A_7}$
To get active low, chip select term should be zero

$$A_2 = A_3$$

$$A_4 \neq A_5$$

$$A_6 \neq A_7$$

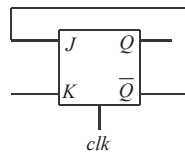
This conditions are satisfied by address
60 H to 63 H.



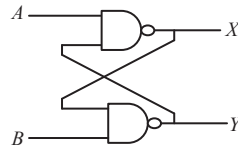
7.

Q_n	J	Q_{n+1}
1	1	1
0	0	0
1	1	1
0	0	0
1	1	1

Sequence is 010101



8.



The given circuit is shown below:

If $A = 1$ $X = 0$

$B = 1$ $Y = 1$

$A = 1$ $X = 0$

$B = 0$ $Y = 1$

$A = 1$ $X = 0$

$B = 1$ $Y = 1$

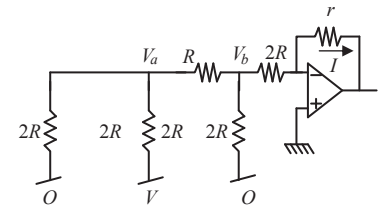
$A = 1$ $X = 0$

$B = 1$ $Y = 1$

9.

	$\overline{Q}_{n-1}$	K_1	Q_{n-1}	K_2	Q_1	Q_2	$\overline{Q}_2$
1 st Clock					0	0	1
2 nd Clock	1	1	0	1	1	0	1
3 rd clock	1	1	1	1	0	1	0
4 th clock	0	1	0	1	0	0	

10.



$$\frac{V_a}{2R} + \frac{V_a - V}{2R} + \frac{V_a - V_b}{R} = 0$$

$$\text{or, } 4V_a = 2V_b + V$$

$$\text{or } \frac{V_b - V_a}{R} + \frac{V_b}{2R} + \frac{V_b}{2R} = 0$$

$$\text{Or, } 2V_b = V_a$$

$$\text{Since } 3V_a = V_a$$

$$\therefore V_b = [V/6]$$

$$\therefore I = [V/12R]$$

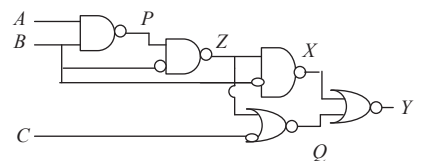
11. Essential prime implicants for the function whose Boolean function is shown:

1	0	1	1
0	0	0	1
1	0	0	0
1	0	0	1

$$12. X = (\overline{A} \overline{B} + \overline{A} B)(\overline{B} C + B C) C$$

$$= (\overline{A} \overline{B} + \overline{A} B) B C = \overline{A} B C = \overline{0} 1 1 = 1$$

13.



$$P = \overline{A} \overline{B}$$

$$Z = \overline{P} \cdot \overline{B} = \overline{P} + B$$

$$X = (\overline{Z} \overline{B}) = \overline{Z} + B$$

$$Q = (\overline{Z} + \overline{C}) = \overline{Z} \cdot C$$

$$\begin{aligned}
 \bar{Y} &= X + Q = \bar{Z} + B + \bar{Z} \cdot C \\
 &= \bar{Z}(1 + C) + B = \bar{Z} + B \\
 &= (\overline{P+B}) + B \\
 &= P \cdot \bar{B} + B = B + P \\
 &= B + \overline{AB} = B + \bar{A} + \bar{B} = \bar{A} \\
 \therefore Y &= A
 \end{aligned}$$

14. V_{in} at Non inverting terminal

$$\frac{V_R}{2^4} (2^3 + 2^1) = \frac{1}{16} \times 10$$

Gain of non inverting amplifier

$$\begin{aligned}
 &= \left(1 + \frac{R_f}{R} \right) \\
 V_o &= \left(1 + \frac{R_f}{R} \right) V_{in} \\
 &= \frac{10}{16} \left(1 + \frac{7}{1} \right) = 5V
 \end{aligned}$$

- 15.

X	Y	Q_n	Q_{n+1}	
0	0	1	1	Hold
0	0	0	0	
0	1	1	1	Set
0	1	0	1	
1	0	1	0	Reset
1	0	0	0	
1	1	1	0	Toggle
1	1	0	1	

In short analysis

$$D = \bar{X}Z + Y\bar{Z}$$

For JK FF $Q_{n+1} = \bar{K}Q + J\bar{Q}$

In present case $D = Q$ for D FF

Hence $Y = J$ and $X = K$

16. Input to S_2 is an OR gate and output of OR gate is C irrespective of the other input 1 or 0.

C	B	A	X
$\bar{C}$	$\bar{B}$	$\bar{A}$	0
			1
			2
$\bar{C}$	B	A	3
			4
C	$\bar{B}$	A	5
C	B	$\bar{A}$	6
			7

$$\begin{aligned}
 y &= \bar{C} \bar{B} \bar{A} + C \bar{B} A + \bar{C} B A + C B \bar{A} \\
 &= \bar{C} (\bar{B} \bar{A} + AB) + C (\bar{B} A + B \bar{A}) \\
 &= \bar{C} (\overline{A \oplus B}) + C (A \oplus B)
 \end{aligned}$$

Where, $(A \oplus B)$

$$\begin{aligned}
 &= \overline{AB + \bar{A}\bar{B}} = (\overline{AB}) + (\overline{\bar{A}\bar{B}}) \\
 &= (\bar{A} + \bar{B}) + (A + B) \\
 &= (A + \bar{B}) + (\bar{A} + B) \\
 &= A \bar{A} + A B + \bar{B} \bar{A} + \bar{B} B \\
 &= 0 + A B + \bar{A} \bar{B} + 0 \\
 &= A B + \bar{A} \bar{B}
 \end{aligned}$$

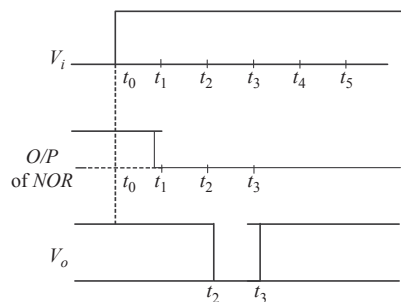
18. The cell is written into by applying the bit line voltage through the transistor to the capacitor, Reading is done by connecting bit line through the gate and sensing the capacitor voltage level.

The read out is destructive Hence the voltage a **cross** the capacitor & bit line is same all the time,

19. Output of 1st EX-OR = $1 \oplus X = \bar{X}$
 Output of 2st EX-OR = $\bar{X} \oplus X = 1$
 Output for even (i.e., 20) EX-OR = 1

- 20.

	t_0	t_1	t_2	t_3
Input to G_1	0	1	1	1
$\bar{G}_1$	1	0	0	0
Input to G_2	0	1	1	1
V_0	1	1	1	0



21. One input with latched digital gates work as monostable multivibrator.
22. Both the statements are true. As T_1 is N type Enhancement MOSFET, So when $V_i > V_g$ it will conduct. When $V_o = 0$, Then T_1 must have zero resistance to extend the earth to output which is only possible when it is in saturation.

23. y_3, y_2, y_1, y_0 can have different value which depends upon the input x_3, x_2, x_1, x_0 value.

Y_3	Y_2	Y_1	Y_0	F
0	0	0	0	0
0	0	0	1	1
0	0	1	0	2
0	0	1	1	3
0	1	0	0	4
0	1	0	1	5 for 2-4-2-1
1	1	0	0	6 for 2-4-2-1
1	1	0	1	7 for 2-4-2-1
1	1	1	0	8 for 2-4-2-1
1	1	1	1	9 for 2-4-2-1

24. Let $P = 1011$ and $Q = 1001$

$$\text{Given, } Y_n = P_n \oplus Q_n \oplus R_n$$

$$Z = R_n Q_n + P_n \bar{R}_n + Q_n \bar{P}_n$$

Now, constructing the truth - table

	P_n	Q_n	R_n	Z_n	Y_n
$n=1$	1	1	0	0	0
$n=2$	1	0	0	0	1
$n=3$	0	0	0	0	0
$n=4$	1	1	0	0	0

From the circuited given, we have

$$R_{n+1} = Z_n, 1 \leq n \leq 3$$

And $Z_4 = Y_5$ (MSB)

Hence, output is 00010 which show that it is a 4-bit subtractor giving $P - Q$

$$\begin{aligned}
 25. V_o &= -V_R \left[\frac{R}{R} d_3 + \frac{R}{2R} d_2 + \frac{R}{4R} d_1 + \frac{R}{8R} d_0 \right] \\
 &= -V_R \left[\frac{d_3}{1} + \frac{d_2}{2} + \frac{d_1}{4} + \frac{d_0}{8} \right]
 \end{aligned}$$

When $V_R = 5V$ and $d_3 = d_2 = d_1 = d_0$

$$\begin{aligned}
 V_o &= -5 \left[1 + 0.5 + 0.25 + 0.125 \right] \\
 &= -9.375
 \end{aligned}$$

In worst Case,

Maximum value V_o due to tolerance 10% increase and 5% increase in numerator and decrease in denominator

$$\begin{aligned}
 V_o &= - \frac{110 \cdot 5.5}{90} + \frac{110 \cdot 5.5}{2 \cdot 90} + \\
 &\quad \frac{110 \cdot 5.5}{4 \cdot 90} + \frac{110 \cdot 5.5}{8 \cdot 90} \downarrow
 \end{aligned}$$

$$\begin{aligned}
 V_o &= \frac{-110 \times 5.5}{90} [1 + 0.5 + 0.25 + 0.125] \\
 &= -12.604
 \end{aligned}$$

Tolerance of $DAC = 12.604 - 9.375$
 $= 34.44\% = 35\%$

26. Let us take input as $= 0100$

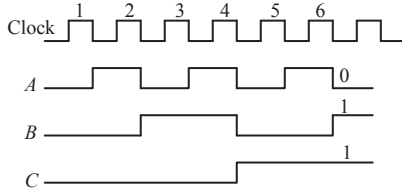
output $= 0100$

∴ This is BCD to binary code converter

27. For TTL logic floating input represent logic 1

$$Y = (\overline{AB+1}) = \overline{AB} \cdot 0 = 0$$

- 29.



To perform the given ripple counter as module-6, the flip-flop should be cleared at the end of sixth pulse.

Since at 6th pulse, $B = C$, then $\overline{B} = \overline{C} = 0$. Hence, the 2-input gate, should be OR gate so that $\text{Clr} = 0$ for all the three flip-flops.

The desire gate should generate 0 as clear is active Low when $CBA = (110)_2$

Input to the desire gate is $\overline{C} \overline{B}$ i.e., 00

OR gate give 0 when both input are 0.

30. The given diagram represent a decade counter

$$\text{Frequency of output} = \frac{10 \times 10^3}{10} = 1 \text{ kHz}$$

31. 3 flip flips are used and it has -ve edge triggering. Hence it is mod 5 down counter. Apply the Trick as below:

- When ever preset is activate it indicate down counter
- When ever clear is activated it indicate up counter

up/down $= CP \oplus Q$, 1 for up and 0 for down

$CP =$ (clock pulse)

$$Q = (O/P)$$

0 = -ve edge; $Q = 1$

1 = +ve edge; $\overline{Q} = 1$

$$= 1 \oplus 1 = 0 \text{ (down counter)}$$

Counting sequence

1 1 1
 1 1 0
 1 0 1
 1 0 0
 0 1 1 (preset state) so Mod 5

32. For LED to emit light, NAND output should be low (o) and input 1, for which AND input to be 1 and ex - oR gate input 0.1 or 1, 0. when S_1 and or S_2 are closed input to the AND Gate is 0. When S_1, S_2 are open input to the AND gate is 1 as also to X-OR gate.

$$f = EA$$

$$E = \overline{B}C + B\overline{C}$$

$$B = A(\overline{B}C + B\overline{C})$$

$$= A\overline{B}C + AB\overline{C}$$

34. V_o is at logic 0. So transistor is in saturation

$$V_{BE} = 0.75 \text{ V}$$

$$\therefore I_R = \frac{0.75}{1K} = 0.75 \text{ mA}$$

$$I_R = 0.75 \text{ mA}$$

$$35. F = \overline{A}BC + AB\overline{C}$$

$$= B[\overline{A}C + A\overline{C}]$$

$$F = B[A + C][\overline{A} + \overline{C}]$$

$$36. I_{DS}(T_1) = I_{DS}(T_2)$$

$$[1/2] K_1 (V_{GS1} - V_t)^2 = [1/2] K_2 (V_{GS2} - V_t)^2$$

$$(5 - V_o - 1)^2 = 9 (V_o - 1)^2$$

$$6(4 - V_o) = 3(V_o - 1)$$

$$\Rightarrow 2(4 - V_o) = V_o - 18 + 1$$

$$\text{or } 3V_o = 9$$

$$V_o = 3$$

37. T Flip-flop will toggle with each trigger pulse clock if $T = 1$

Q_n	$Q_{n+1} = \overline{Q}_n$
$Q_0 = 1$	0
$Q_1 = 1$	0
$Q_2 = 0$	1

Output $Q_2Q_1Q_0 = 100$

38. Address range of chip 1 and chip 2 $\rightarrow$

$$\left. \begin{array}{l} A_0 - A_7 \\ 00 - FF \end{array} \right\} \begin{array}{l} A_8 A_9 A_{10} - A_{15} \\ 00FF - 00 \\ 01FF - 00 \\ 10FF - 00 \\ 11FF - 00 \end{array} \quad \begin{array}{l} \overline{A}_9 \overline{A}_8 \\ \overline{A}_9 \overline{A}_8 \end{array}$$

$A_8 \overline{A}_9 \rightarrow$ selecting chip # 1 [Address range is 100 - 1FF]

$\overline{A}_8 A_9 \rightarrow$ selecting chip # 2 [Address range is 200 - 2FF]

Address range is 100 - 2 FF

Since $A_{10} - A_{15}$ are not used, the address range can be 100 - 2 FF (or) 500 - 6FF (or) 900 - AFF,

For the address space F800 - F9FF chip # 1 and chip # 2 are not selected

- 39.

	$\overline{A} \overline{B}$	$\overline{A} B$	AB	$A \overline{B}$
$\overline{C} \overline{D}$	1	0	0	1
$\overline{C} D$	0	d	0	0
CD	0	0	d	1
$C \overline{D}$	1	0	0	1

$$F = \overline{B} \overline{D} + A \overline{B} C$$

40. In one cycle

Q_2	Q_1	Q_0
D_3	D_2	D_0
0	0	0 $\rightarrow$ 0
0	0	1 $\rightarrow$ 1
0	0	1 $\rightarrow$ 2
0	0	1 $\rightarrow$ 3
1	0	0 $\rightarrow$ 8
1	0	0 $\rightarrow$ 9
1	0	0 $\rightarrow$ 10
1	0	1 $\rightarrow$ 11

** From third level there is abrupt jump to eight level

41. Present state Next state

Q_1	Q_0	D_1	D_0
0	0	0	1
0	1	1	1
1	1	1	0
1	0	0	0

$$D_0 = \overline{Q}_1; D_1 = Q_0$$

43. As given TTL circuit is NOT gate

$V_i = 2.5 \text{ V}$ high is applied. Output is low only when the earth is extended to output it means Q_3 is in saturation mode and Q_4 is cut off as Q_3 and Q_4 always behave negatively. Q_2 work in normal active but Q_1 in reverse active as $V_i = 2.5$ applied to emitter of Q_1 .

44. $Y = I_1 + I_2$

$$Y = \overline{A}B + A\overline{B} = A \oplus B$$

$$X = \overline{Y}C + Y\overline{C} = Y \oplus C = A \oplus B \oplus C$$

$$= \overline{A}B\overline{C} + A\overline{B}\overline{C} + \overline{A}B\overline{C} + ABC$$

45. For $X = 0 \Rightarrow P = 1$

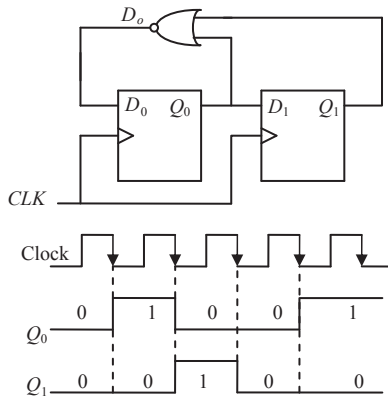
∴ for NAND gate $0X$ or $X0$ gives 1 as output

Then Q becomes 0 for 11 input

The NAND action is represented by table given below

X	Y	P	Q
0	1	1	0
0	0	1	1
1	1	1	0 or 0/1

46.



NOR GATE		
Q_0	Q_1	D_0
0	0	1
1	0	0
0	1	0
0	0	1
1	0	0

Sequence is

 $\therefore Q_0 Q_1$ 00,01,10,00,01...

47.

Q_0	Q_1	Q_2	$\bar{Q}_2$
1	0	1	0
0	1	0	1
1	0	1	0

48.

$$\begin{aligned}
 (A \oplus B) \cdot C &= (\bar{A}B + A\bar{B}) \cdot C \\
 &= (\bar{A}B + A\bar{B}) + \bar{C} \\
 &= (\bar{A}B) (\bar{A}\bar{B}) + \bar{C} \\
 &= (\bar{A} + \bar{B}) (\bar{A} + \bar{B}) + \bar{C} \\
 &= (A + \bar{B}) (\bar{A} + B) + \bar{C} \\
 &= \bar{A}A + AB + \bar{A}\bar{B} + \bar{B}B + \bar{C} \\
 &= 0 + \bar{A}\bar{B} + AB + 0 + \bar{C} \\
 &= AB + \bar{A}\bar{B} + \bar{C}
 \end{aligned}$$

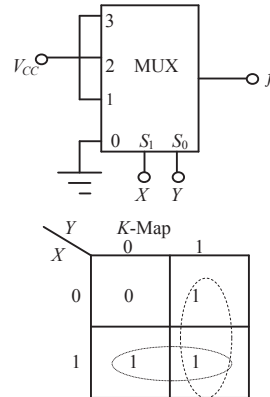
50. $\bar{F} = \bar{A}\bar{C}$

$$\bar{F} = \bar{A}\bar{C}$$

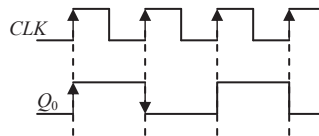
$$\begin{aligned}
 F &= \overline{\bar{A}\bar{C}} \\
 &= A + C
 \end{aligned}$$

Note: Minimal product of sums $F = A + C$

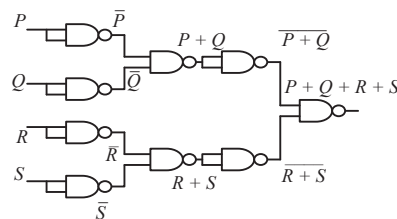
51.

From the map, $f = x + y$

52.

The frequency of $Q = \frac{f_0}{2} = \frac{10}{2} = 5\text{kHz}$

53.



54. The given figure is T flip as this a flip-flop design problem solution. This can be checked by truth table too. It have one input only.

$$Y = AB + \bar{A}\bar{B}$$

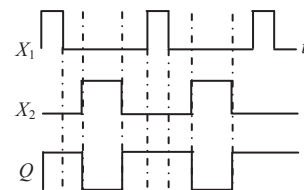
excitation table for T and D

Q_n	Q_{n+1}	D	T
0	0	0	0
0	1	1	1
1	0	0	1
1	1	1	0

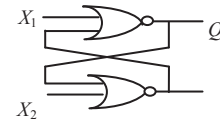
Expression for D in term of T

$$D = \bar{Q}_n T + Q_n \bar{T}$$

55.

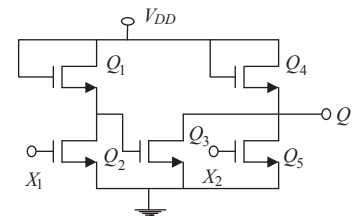


X_4	X_2	Q
1	0	1
0	0	1
0	1	0



Thus (a) satisfy the condition

$$56. \bar{X}_1 + X_2 = X_1 \cdot \bar{X}_2$$



X_1	X_2	Q_1	Q_2	Q_3	Q_4	Q_5	O/P
0	0	ON	OFF	ON	ON	OFF	0
0	1	ON	OFF	ON	ON	ON	0
1	0	ON	ON	OFF	ON	OFF	1
1	1	ON	ON	OFF	ON	ON	0

57.

Case 1

$$\begin{aligned}
 x_1 = 1 &\rightarrow 1 \\
 x_2 = 1 &\rightarrow 1 \\
 Q = 0 &\rightarrow 1
 \end{aligned}$$

Case 2

$$\begin{aligned}
 x_1 = 1 &\rightarrow 1 \\
 x_2 = 1 &\rightarrow 0 \\
 Q = 1 &\rightarrow 0
 \end{aligned}$$

Therefore out is unstable.

58. The voltage is becoming zero and current is increasing. Thus the switch is in turn ON condition average power loss during

$$\text{Switch} = \frac{VI}{2}(t_1 + t_2)$$

59. Thyristor can avoid the voltage of either polarity. Its operation depends on gate trigger.

60. Base of Q_2 always at $\leq 0.7\text{V}$ So Q_2 is ON. Q_1 will conduct in reverse active region as collector potential should always $\geq$ base potential.

$$V_{CB} \geq 0$$

$$V_{CE} > 0$$

So, Q_1 is reverse ON

61.

BC	00	01	11	10
A				
0		1		1
1	1			1

Decimal	A	B	C	Uni selected	Output
0	0	0	0	I ₀	0
1	0	0	1	I ₁	1←
2	0	1	0	I ₂	1←
3	0	1	1	I ₃	0
4	1	0	0	I ₄	1←
5	1	0	1	I ₅	0
6	1	1	0	I ₆	1←
7	1	1	1	I ₇	0

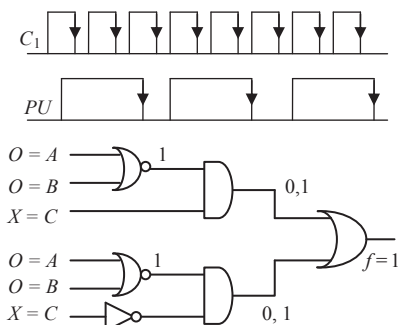
$$F(A,B,C) = \oplus (1, 2, 4, 6)$$

62.

A	B	C	D	Y	S = A + B + C + D + Y
0	0	0	0	0	0
0	0	0	1	1	0
0	0	1	0	1	0
0	0	1	1	0	0
0	1	0	0	1	0
0	1	0	1	0	0
0	1	1	0	0	0
0	1	1	1	1	0
1	0	0	0	1	0
1	0	0	1	0	0
1	0	1	1	1	0
1	1	0	0	0	0
1	1	0	1	1	0
1	1	1	0	1	0
1	1	1	1	0	0

Sum is always zero and zero is a even term therefore, option (b) is correct

63. From the diagram backward analysis. The result is as output will be 1 when $A = 0, B = 0, C = X = 0$ or 1

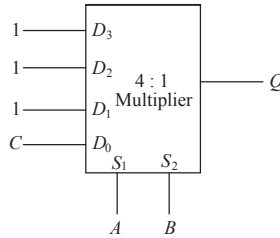


64.

AB	00	01	11	10
C				
0		1		1
1	1		1	

$$\begin{aligned} 1^{\text{st}} \text{ Pair (010 to 001)} &= \bar{A} [B \oplus C] \\ 2^{\text{nd}} \text{ pair (100 to 100)} &= A [B \odot C] \\ Y &= \bar{A} (B \oplus C) + A [B \odot C] \\ &= \bar{A} (B \oplus C) + A (\overline{B \oplus C}) \\ &= A \oplus B \oplus C \end{aligned}$$

65.



A	B	D _n	
0	0	C	D ₀
0	1	1	D ₁
1	0	1	D ₂
1	1	1	D ₃

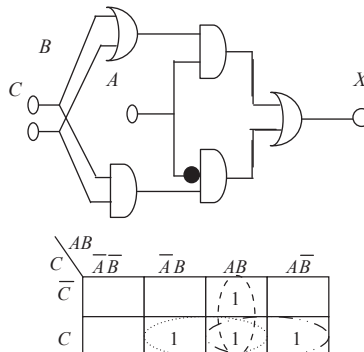
$A = 0, B = 0, D_0$ is selected
Therefore, $A = 0, B = 0, Q = C$
For the rest of A and $B, Q = 1$
Therefore, $Q = A + B + C$

67. Output of EX-OR gate if both input are different i.e., in present case both expect waveforms have a phase difference of $T/2$ for mean reading of PMMC

68. T_1 (Fixed time)

$$\begin{aligned} &= 2^{n-1} \times T_C \frac{2^{n-1} - 1}{\text{Clock frequency}} \\ &= \frac{2^{8-1}}{4 \times 10^6} = 0.032 \text{ ms} \end{aligned}$$

70.



71. The given expression have a group of and pair
From the k-map,
Output (Y)

73.

Q ₀	Q ₁	J ₁ = (Q ₀) K ₁ (1)	J ₀ (Q ₁) K ₀ (1)
0	0	0	1
0	1	0	1
0	0	0	1
0	1		

CHAPTER 9

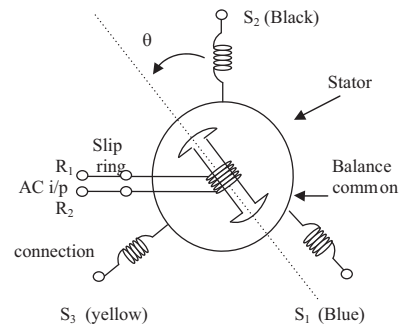
LEVEL 1

- The root locus state from the poles at $k = 0$ and ends at zero at $k = \infty$.
- A unit impulse functions on differentiation results in (a) unit doublet
- Root locus
- Power amplification
- A stepper motor is an electromechanical device which-actuates a train of step angular (or linear) movements in response to a train of input pulses on one to one basis.
- Inversely proportional or gain constant.
- A windscreen wiper.
- Stepper motor.
- Number of Separate Root Loci
The total number of root loci is equal to the order of equation $F(s) = 1 + G(s)H(s) = 0$
 N = Number of branch of RL
 P = Number of finite Pole of GH
 Z = Number of finite zero of GH
 $N = Z$ if $Z > P$
 $= P$ if $P > Z$

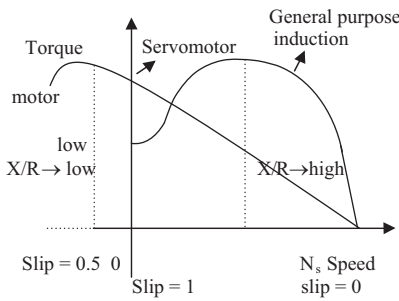
21.

T	K _p	K _v	K _a	$e_{ss} = \frac{R}{1+K_p}$	$e_{ss} = \frac{R}{K_v}$	$e_{ss} = \frac{R}{K_a}$
0	K	0	0	$\frac{R}{1+K_p}$	∞	∞
1	∞	K	0	0	$\frac{R}{K_v}$	∞
2	∞	∞	K	0	0	$\frac{R}{K_a}$
3	∞	∞	∞	0	0	0

22.



23. Torque speed characteristic of AC servomotor:



Torque speed characteristic of AC servomotor

R → resistance of rotor

X → Inductance of rotor

Difference between general purpose Induction motor and AC servomotor:

- $\left(\frac{X}{R}\right)_{\text{servomotor}} < \left(\frac{X}{R}\right)_{\text{General purpose induction motor}}$
- Torque speed characteristics is linear for A.C. servomotor, whereas it is non-linear for general purpose induction motor.

24. Characteristic of Close loop system

- Reduces the effect of disturbance signal
- Reduces the steady state error
- Improve/satisfies the transient and frequency response performance.
- Reduce/satisfies sensitivity to parameter change i.e., reduction of parameter variation.

25. Unit-Ramp (Velocity) Input:

$$R(s) = \frac{1}{s^2}$$

$$e_{ss} = \lim_{s \rightarrow 0} \frac{s(1/s^2)}{1 + G(s)} = \frac{1}{K_p}$$

where $K_p = \lim_{s \rightarrow 0} sG(s)$ is known as **velocity error constant**

Type	K_p	K_v	K_a	$e_{ss} = \frac{1}{R/1+K_p}$	$e_{ss} = \frac{1}{R/K_v}$	$e_{ss} = \frac{1}{R/K_a}$
0	K	0	0	$R/1+K_p$	∞	∞
1	∞	K	0	0	R/K_v	∞
2	∞	∞	K	0	0	R/K
3	∞	∞	∞	0	0	0

26. If the transfer function of a linear time invariant system has pole zero cancellation, the system will be either not state controllable or observable, depending on how the state variables are

defined. If the transfer function does not have pole zero cancellation the system can always be represented by completely controllable and observable state model.

29. In a servo system, the gear backlash may cause low level oscillations or chattering phenomenon and the system may even turn unstable for large backlash.

31. Ramp function

In a first order hold, the last two signal samples are used to reconstruct the signal for the current sampling period. Which results into a Ramp function.

32. Phase-lead compensation results in increased bandwidth i.e., reduction in setting time and thus speed of the time response is improved. That means rise time of close loop system is reduced.

33. Liapunov's method is used for stability analysis of non-linear control system. Piecewise linear method is also used for general investigation of non-linear system in addition to Phase plane and describing function method.

35. The disadvantages of static error constants (K_p, K_v, K_a) is that they do not give information on the steady-state error when inputs are other than the three basic types-step, ramp and parabolic. Another difficulty is that the error constants fail to indicate the exact manner in which error function changes with time. The dynamic error may be evaluated using the dynamic error coefficients-the concept generalised to include inputs of almost any arbitrary function of time.

36. Cascade compensation is quite satisfactory and economical in most cases.

38. Offset error is inversely proportional to gain

$$e_{ss} |_{\text{offset}} = \frac{A}{1 + k_p}$$

State-state error i.e., offset is unaffected by derivative control.

39. Refer tachogenerator feedback compensation.

41. Transfer function of system

$$\frac{C}{R} = \sum_K \frac{M_K \Delta_K}{\Delta}$$

42. Steady state value of system is given by final value theorem.

$$t(\infty) = \lim_{t \rightarrow \infty} f(t) = \lim_{s \rightarrow 0} [s f(s)]$$

43. $H(s) = F_o(s)/F_i(s)$

44. A transfer function which has one or more zero in the right half S-plane is known as non minimum-phase transfer function.

45. Asymptotes Angles are given by

$$\theta_k = \frac{(2K+1)\pi}{P-Z}$$

Where $K = 0, 1, 2, \dots, [(P-Z)-1]$

i.e., Number of Asymptotes = $P-Z$

47. In a LVDT, the two secondary voltages Vary unequally depending on the core position

48. Let, $f(t) = A \sin \omega t$

$$\frac{df(t)}{dt} = A \omega \cos \omega t$$

A **differentiator** has transfer function whose amplitude increases linearly with frequency

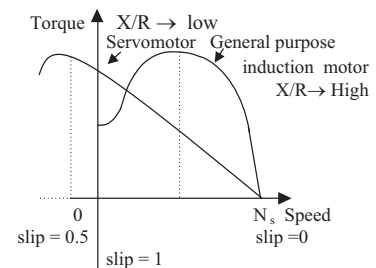
49. Introduction of **integral action** in the forward path of a unity feedback system results in a System with no steady state error.

50. For a linear control system with no poles in R.H.S of S-plane. But there may be case of having repeated poles on $j\omega$ axis which makes output unbounded.

51. In phase lead compensation the zero is near to origin as compared to pole. Hence the effect of zero is dominant. This network allows to pass high frequencies and attenuates the low frequencies. This network increase the band width. It also improves the speed of response and overshoot it mean decreases both rise time and overshoot which makes system faster. However, the steady state does not show appreciable improvement.

52. Exists $Ax = b$, b should be in column space of A .

- 53.



Torque speed characteristic of AC servomotor

R → resistance of rotor

X → Inductance of rotor

Difference between general purpose Induction motor and AC servomotor:

$$3. \left(\frac{X}{R}\right)_{\text{servomotor}} < \left(\frac{X}{R}\right)_{\text{General purpose induction motor}}$$

4. Torque speed characteristics is linear for A.C. servomotor whereas it is non-linear for general purpose induction motor.

5. Rotor is generally drag cup type or squirrel cage type.
6. Ac servomotor is an example of type 1 order 2 system.

54. Feed back path sensitivity i.e., sensitivity with change in G .

$$S_H^T = \frac{-GH}{1+GH} = -1$$

Forward path sensitivity, i.e., sensitivity with change in G .

$$S_G^T = \frac{1}{1+GH} = 0$$

Feed back path is more sensitive than forward path

56. A temperature control system is usually very sluggish. To improve its dynamics a PD controller can be used.

An integral system always makes a system sluggish (slow). The response can be made faster by increasing the gain but oscillation will increase which will tend to drive the system towards instability. This is not desirable. Hence to improve the dynamics, a derivative controller is always introduced.

57. In a **seismic pick-up for getting** an output proportional to acceleration it is desirable to have a natural frequency very large in comparison to frequency of input and a damping ratio around 0.7.
58. Integration reduces the offset caused by proportional controller action. It integrates area under curve thus minimizing the offset.
59. When proportional controller action is used and time delay is introduced, then gain margin is not affected and phase margin also remains the same.
60. Selsyn used for error detection
65. Linear variable differential transformer has one primary coil and two secondary coils connected in opposition.
69. Compare with standard 2nd order system i.e.,

$$G(s) = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

Functions:

1. $\frac{1}{s^2 + s + 1} \Rightarrow \omega_n = 1, \delta = \frac{1}{2} = 0.5$
2. $\frac{4}{s^2 + 2s + 4} \Rightarrow \omega_n = 2, \delta = \frac{2}{2 \times 2} = 0.5$
3. $\frac{2}{s^2 + 2s + 2} \Rightarrow \omega_n = \sqrt{2}, \delta = \frac{2}{2\sqrt{2}} = 0.07$
4. $\frac{1}{s^2 + 2s + 1} \Rightarrow \omega_n = 1, \delta = \frac{2}{2} = 1$

$$5. \frac{3}{s^2 + 6s + 3} \Rightarrow \omega_n = \sqrt{3}, \delta = \frac{6}{2\sqrt{3}}$$

$$\uparrow = \frac{6}{3.5} = 1.8$$

$\delta < 1$ represent under damped system i.e., 1, 2, 3 function

$$70. E(s) = \frac{R(s)}{1+G(s)H(s)}$$

for a unity feedback system

$$E(s) = \frac{R(s)}{1+G(s)}$$

$$e_{ss} = \lim_{s \rightarrow 0} sE(s) = \lim_{s \rightarrow 0} \frac{sR(s)}{1+G(s)}$$

$$r(t) = u(t) + t u(t) + \frac{t^2}{2} u(t)$$

$$R(s) = \frac{1}{s} + \frac{1}{s^2} + \frac{1}{s^3}$$

$$e_{ss} = \lim_{s \rightarrow 0} \frac{1}{1+G(s)} + \lim_{s \rightarrow 0} \frac{1}{sG(s)} + \lim_{s \rightarrow 0} \frac{1}{s^2 G(s)}$$

$$= \frac{1}{1+K_p} + \frac{1}{K_v} + \frac{1}{K_a}$$

71. Poles with positive real part denote unstable system.

73. From given Bode plot

$$G(s)H(s) = \frac{K}{j\omega} a s H(s) = 1$$

$$\angle G(j\omega)H(j\omega) = -90^\circ$$

$$\therefore \text{Phase margin, (maximum)} = -90^\circ + 180^\circ = 90^\circ$$

$$74. q(s) = a_0 s^3 + a_1 s^2 + a_2 s + a_3 = 0$$

R.H table

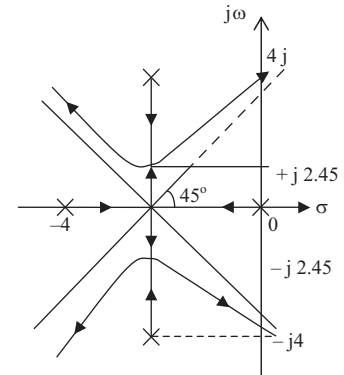
s^3	a_0	a_2	0
s^2	a_1	a_3	0
s^1	$\frac{a_1 a_2 - a_0 a_3}{a_4}$		0
s^0	a_3		

For stable system

$$\frac{a_1 a_2 - a_0 a_3}{a_1} \geq 0$$

$$a_1 a_2 \geq a_0 a_3$$

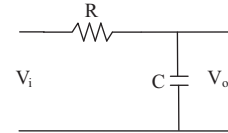
$$75. G(s)H(s) = \frac{K}{s(s+4)(s^2+4s+20)}$$



It can be seen from root locus diagram that there are three break away points that $s = -2, s = (-2 \pm 2.45j)$

This can be found solving for $\frac{dK}{ds} = 0$

76. RC phase lag network is given by



$$\frac{V_o}{V_i} = \frac{1}{sC} \cdot \frac{1}{1 + sC R}$$

$$\frac{V_o}{V_i} = \frac{1}{RCs + 1}$$

79. Time response is proportional to the band-width of the system. Higher the bandwidth faster is the response.

$$80. e_{ss} = \lim_{s \rightarrow 0} \frac{sR(s)}{1+G(s)H(s)}$$

$$\text{Where } R(s) = \left(\frac{3}{s} - \frac{6}{s^3} \right)$$

$$\therefore e_{ss} = \lim_{s \rightarrow 0} \frac{s \cdot \frac{3}{s}}{1+G(s)H(s)}$$

$$- \lim_{s \rightarrow 0} \frac{s \cdot \frac{6}{s^3}}{1+G(s)H(s)}$$

$$= \frac{3}{1 + \lim_{s \rightarrow 0} G(s)H(s)}$$

$$= \frac{6}{\lim_{s \rightarrow 0} s^2 + \lim_{s \rightarrow 0} s^2 G(s)H(s)}$$

$$= \frac{3}{1+k_p} - \frac{6}{k_a}$$

Another approach

$$\begin{aligned}
 I_{ss} &= \lim_{s \rightarrow 0} s E(s) = \lim_{s \rightarrow 0} \frac{sR(s)}{1+G(s)} \\
 &= \lim_{s \rightarrow 0} \left(\frac{1}{s} - \frac{2}{s^3} \right) \frac{1}{1+G(s)} \\
 &= \lim_{s \rightarrow 0} \left(1^3 - \frac{6}{s^2} \right) \frac{1}{1+G(s)} \\
 &= \lim_{s \rightarrow 0} \frac{3}{1+G(s)} - \lim_{s \rightarrow 0} \left(\frac{6}{s^2 + s^2 G(s)} \right) \\
 &= \frac{3}{1+k_p} - \frac{6}{k_a}
 \end{aligned}$$

$$81. V_{s1n} = K v_r \sin \omega_c t \cos(\theta + 120)$$

$$V_{s2n} = K v_r \sin \omega_c t \cos \theta$$

$$V_{s3n} = K v_r \sin \omega_c t \cos(\theta + 240)$$

$$\begin{aligned}
 V_{s2} V_{s2} &= U_{s1n} - U_{s2n} \\
 &= \sqrt{3} K v_r \sin(\theta + 240) \sin \omega_c t
 \end{aligned}$$

$$\begin{aligned}
 V_{s2} V_{s3} &= U_{s2n} - U_{s3n} \\
 &= \sqrt{3} K v_r \sin(\theta + 120) \sin \omega_c t
 \end{aligned}$$

$$\begin{aligned}
 V_{s3} V_{s1} &= U_{s3n} - U_{s1n} \\
 &= \sqrt{3} K v_r \sin \theta \sin \omega_c t
 \end{aligned}$$

$$\therefore V_{s3s1} \text{ will be taken for zeroing}$$

Another approach

If the rotor axis of synchro transmitter is along the axis of S_2 stator winding then maximum voltage is induced in the stator coil S_2 and the terminal voltage V_{s3}, V_{s1} is zero. This position of the rotor is defined as the electrical zero of the transmitter and is used as reference for specifying the angular position of the rotor.

$$84. \text{ Characteristic equation of the system is } 1 + GH = 0$$

$$s^2 + s + k = 0$$

$$\therefore 2\delta\omega_n = 1 \text{ and } \omega_n = \sqrt{k}$$

$$\therefore \delta = \frac{1}{2\sqrt{k}} = 0 \text{ as } k \rightarrow \infty$$

$$85. \text{ We can write OLTF as}$$

$$G(s)H(s) = \frac{k(s+1)}{s(s+4)(s^2+2s+2)}$$

$$Z = 1,$$

$$P = 4$$

$$\theta = \frac{(2k+1)}{P-Z} 180^\circ$$

$$= \frac{(2k+1)180^\circ}{4-1}$$

$= 60^\circ, 180^\circ, 300^\circ$ for $k = 0, 1, 2$ respectively.

LEVEL 2

- For series RLC circuit excited by unit step, the damping ratio δ is actual resistance R upon the critical resistance R_c [the resistive value so that no oscillations occur]

$$R_c = 2\sqrt{\frac{L}{C}}$$

$$\delta = \frac{R}{R_c} = \frac{R}{2\sqrt{L/C}}$$

- Characteristic equation of this system is

$$s^2 + 6s + 9 = 0$$

$$\text{or } (s+3)^2 = 0$$

$$\text{or } s = -3$$

The solution will be of the form

$$y = (K_1 + K_2 t) e^{-3t}$$

$$3. F(s) = s^4 + 2s^3 + 3s^2 + 6s + k$$

Apply RH table

s^4	1	3	K
s^3	2	6	0
s^2	1	3	0
s^1	0	K	

Problem: When in one row of first (column) a member is zero.

Advice: modify the original characteristic equation S by $(1/p)$, make new equation in p and solve by RH method in p .

Modification is given equation

$$\left(\frac{1}{p}\right)^4 + 2\left(\frac{1}{p}\right)^3 + 3\left(\frac{1}{p}\right)^2 + 6\left(\frac{1}{p}\right) + K = 0$$

$$\text{or } Kp^4 + 6p^3 + 3p^2 + 2p + 1 = 0$$

p^4	K	3	1
p^3	6	2	0
p^2	$\frac{18-2K}{6}$	6	0
p^1	$\frac{2(18-2K)}{6} - 36$	0	
	$= \frac{18-2K-108}{3}$		

- $K > 0$
- $\frac{9-K}{3} \geq 0 \Rightarrow 9 \geq K$
- $(18-2K-108) \geq 0$
 $\Rightarrow -90 \geq 2K$

$$\Rightarrow -45 \geq 2K$$

$\therefore$ unstable for all value of K

- In phase lag network bandwidth and gain cross over frequency decreases $\rightarrow$ **Refer details**

$$5. \frac{49}{s^2 + 16s + 49} = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

$$\omega_n = 7$$

$$2\delta\omega_n = 16 \Rightarrow \delta = \frac{16}{14} = 1.14$$

As $\delta > 1$ therefore no over shoot

- Characteristic equation $= 1 + GH = 0$

$$1 + \frac{K(s+10)(s+20)}{s^2(s+2)} = 0$$

$$\text{or } s^2(s+2) + K(s+10)(s+20) = 0$$

$$\text{or } s^3 + 2s^2 + K(s^2 + 30s + 200) = 0$$

$$\text{or } s^3 + (2+K)s^2 + 30Ks + 200K = 0$$

Apply RH table

s^3	1	30K
s^2	2+K	200K
s^1	$\frac{60K + 30K^2 - 200K}{2+K}$	0
s^0	200K	

$$30K^2 - 140K = 0$$

$$(30K - 140)K = 0$$

$$K \geq \frac{140}{30} = 4.6$$

$$K = 5$$

$$8. = \frac{\sum \text{finite poles of GH} - \sum \text{finite zero of GH}}{P - Z}$$

$$\sigma_a = \frac{(0-1-3)}{3} = -1.33$$

- Characteristic equation $= 1 + GH = 0$

$$s(s+a)(s+b) + k = 0$$

$$\text{or, } s^3 + (a+b)s^2 + abs + k = 0$$

RH Table

s^3	1	ab
s^2	$a+b$	k
s^1	$ab - \frac{k}{a+b}$	
s^0	k	

For stable system all the elements of first column of RH table should have same sign. In present case positive.

$$\therefore 0 < k < ab(a+b)$$

$$10. e_{ss}(t) = \lim_{s \rightarrow 0} \frac{sR(s)}{1 + G(s)H(s)}$$

$$\lim_{s \rightarrow 0} \frac{s \cdot \frac{1}{s^2 + 1}}{1 + \frac{1}{s^2 + s}} = \lim_{s \rightarrow 0} \frac{s \cdot s(s+1)}{(s^2 + s+1)(s^2 + 1)}$$

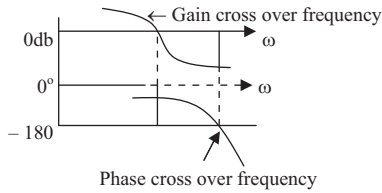
$$= \lim_{s \rightarrow 0} \frac{s^2(s+1)}{(s^2 + s+1)(s^2 + 1)} = 0$$

11. Setting time for 2% tolerance

$$t_s = \frac{4}{\sigma} = \frac{4}{\xi \omega_n}$$

$$12. x = -\frac{1}{2}$$

13.



$$PM = 180 + \angle GH(\omega_c)$$

At phase cross over frequency.

Phase is $-180^\circ = -\pi$ rad

$$\text{Then, } -\tan^{-1} \omega_c - \tan^{-1} 2\omega_c - \tan^{-1} 3\omega_c = -\pi$$

$$\tan^{-1} \omega_c + \tan^{-1} 2\omega_c = \pi - \tan^{-1} 3\omega_c$$

$$\tan^{-1} \frac{\omega_c + 2\omega_c}{1 - 2\omega_c \cdot \omega_c} = \pi - \tan^{-1} 3\omega_c$$

$$[\tan(\pi - \theta) = \tan(-\theta)]$$

$$\tan^{-1} \frac{3\omega_c}{1 - 2\omega_c^2} = \tan^{-1}(-3\omega_c)$$

$$\frac{3\omega_c}{1 - 2\omega_c^2} = -3\omega_c \quad \text{or} \quad -1 + 2\omega_c^2 = 1$$

$$2\omega_c^2 = 2 \quad ; \quad \omega_c = \pm 1 \text{ rad}$$

14. The characteristic equation of polynomial

$$s^4 + s^3 + 2s^2 + 2s + 3 = 0$$

Apply the RH table

s^4	1	2	3
s^3	1	2	
s^2	$0 = \varepsilon$	3	
s^1	$2 - \frac{3}{\varepsilon}$		

When $\varepsilon = 0^+$

There are two sign changes in the first column. Therefore, there are two roots in RHS of s -plane.

15. Input $r(t) = u(t)$

$$R(s) = \left(\frac{1}{s}\right)$$

$$c(t) = 1 - 10e^{-t}$$

$$C(s) = \frac{1}{s} - \frac{10}{s+1} = \frac{(1-9s)}{s(s+1)}$$

$$\text{Therefore, } H(s) = \frac{C(s)}{R(s)} = \frac{(1-9s) \times s}{s(s+1)} = \frac{(1-9s)}{(s+1)}$$

16. Each zero gives slope of 20db/decade and each poles gives -20db/decade slope. Therefore, the slope of higher frequency asymptotes in Bode magnitude plot will be -40 db/decade .

$$T(s) = \frac{(s+Z_1)(s+Z_2)}{s^2(s+p_1)(s+p_1^*)}$$

$$17. \frac{E_0(s)}{E_1(s)} = \frac{\left(S + \frac{1}{R_1 C}\right)}{S + \frac{R_2 + R_1}{R_1 C(R_2)}}$$

$$\text{Let } \tau = R_1 C, \quad \alpha = \frac{R_2}{R_1 + R_2} < 1$$

$$\frac{E_0(s)}{E_1(s)} = \left(\frac{S + \frac{1}{\tau}}{S + \frac{1}{\alpha \tau}} = \frac{S+a}{S+b} \right) = \frac{\alpha(1+S\tau)}{(1+S\alpha\tau)}; \alpha < 1$$

18. Constant-N Circles:

$$\text{Phase angle of } T(j\omega) = \frac{x+jy}{1+x+jy}$$

$$\alpha = \tan^{-1}\left(\frac{y}{x}\right) - \tan^{-1}\left(\frac{y}{x+1}\right) = \tan^{-1}\left(\frac{y}{x^2 + y^2 x}\right)$$

$$\tan \alpha = \frac{y}{x^2 + x + y^2} = N$$

$$\text{so } \left(x + \frac{1}{2}\right)^2 + \left(y - \frac{1}{2N}\right)^2 = \left(\frac{N^2 + 1}{4N^2}\right)$$

This gives circle with center at $\left(-\frac{1}{2}, \frac{1}{2N}\right)$

$$\left(\frac{1}{2N}\right) \text{ and having radius } = \frac{\sqrt{(N^2 + 1)}}{2N}$$

As center is at $[-1/2] + j0$,

$$\left(\frac{-1}{2}\right) + j0$$

$$N = \infty$$

Therefore, Phase angle, $\alpha = \tan^{-1} N = \pi/2$.

19. Constant-M Circles

Consider any point $G(j\omega) = x + jy$, on the polar plot of $G(j\omega)$. The closed-loop frequency response is

$$T(j\omega) = \frac{C(j\omega)}{R(j\omega)} = \frac{G(j\omega)}{1 + G(j\omega)} = \frac{x+jy}{1+x+jy} = Me^{j\alpha} \quad (1)$$

From equation. (1), the magnitude M is given by

$$M = \frac{|x+jy|}{|1+x+jy|} = \left[\frac{x^2 + y^2}{(1+x)^2 + y^2} \right]^{1/2}$$

$$\text{or } M^2 = \frac{x^2 + y^2}{(1+x)^2 + y^2}$$

Rearranging this equation, we get

$$y^2 + \left[x + \frac{M^2}{M^2 - 1} \right]^2 = \frac{M^2}{(M^2 - 1)^2} \quad (2)$$

Equation (2) is the equation of circle with center at

$$x_0 = -\frac{M^2}{M^2 - 1}; y_0 = 0 \quad (3)$$

$$\text{and with radius } r_0 = \frac{M}{M^2 - 1} \quad (4)$$

given M-circle equation

$$x^2 + 2.25x + y^2 = -1.125$$

$$\text{or, } (x + 1.125)^2 + y^2 = (1.125)^2 - 1.125 \quad (5)$$

From equation (2) and (5) we get

$$\frac{M^2}{M^2 - 1} = 1.125$$

$$\text{or, } M = 3$$

20. Standard N circle equation is given as

$$\left(x + \frac{1}{2}\right)^2 + \left(y^2 + \frac{1}{2N}\right) = \frac{N^2 + 1}{4N^2} \quad (1)$$

Which gives centre at $-\frac{1}{2}, \frac{1}{2N}$

$$x^2 + x + y^2 = 0$$

$$\text{or } \left(x + \frac{1}{2}\right)^2 + y^2 = \frac{1}{4} \quad (2)$$

From equation (1) and (2)

$$\text{Therefore, } \frac{1}{2N} = 0$$

Therefore $\alpha = \tan^{-1} N = \pi/2$

21. Characteristics equation

$$s^6 + 2s^5 + 8s^4 + 12s^3 + 20s^2 + 16s + 16 = 0$$

Apply the RH criteria

s^6	1	8	20	16
s^5	2	12	16	
s^4	1	6	8	
s^3	2	12	16	
s^2	1	6	8	
s^1	0	0	0	

As the term in the s^3 - row are all zero, the Routh's test break down. Now the auxiliary polynomial,

$$A(s) = s^4 + 6s^2 + 8$$

Its derivative is $A(s)/ds = 4s^3 + 12$

Now rearrange the RH array is

s^3	4	12	0
s^2	1	3	0
s^1	3	8	
s^0	1/3	0	
s^0	8		

Now solving the auxiliary polynomial

$$= s^4 + 6s^2 + 8 = 0$$

gives the roots on the $j\omega$ -axis is

$$s^2 = \frac{-6 \pm 2}{2} = -4, -2$$

$$\therefore s = \pm j2, \pm j\sqrt{2}$$

$$S = \pm j\sqrt{2} \text{ and } s = \pm j2.$$

There number of roots on $j\omega$ axis = 4

22. Output $y(t) = t^2 e^{-t}$

Input $x(t) = u(t)$

$$Y(s) = \frac{2}{(s+1)^3} \cdot X(s) = \frac{1}{s}$$

$$\therefore H(s) = \frac{y(s)}{x(s)} = \frac{2s}{(s+1)^3}$$

23. Proportional band is the % change in the input to the controller (error signal) required to cause 100 % change in the output of the actuator.

$$\text{Proportional band} = \frac{\text{error}}{\Delta \text{Gain}}$$

24. (a) Phase margin is the phase angle lagging, in short of 180° , at the frequency corresponding to a gain of 1 i.e., 0 db gain

(b) Gain margin is the value by which the gain falls short of unity, at a frequency corresponding to 180° phase lag

$$\text{Gain margin Kg} = \left| \frac{1}{G(j\omega_1)} \right|$$

(c) Routh-Hurwitz criterion can determine the degree of stability i.e., absolute stability only

25. Constant N circles equation is

$$\left(X + \frac{1}{2} \right)^2 + \left(Y - \frac{1}{2N} \right)^2 = \frac{1}{4} + \left(\frac{1}{2N} \right)^2$$

It crosses the real axis when $y = 0$ the above equation is satisfied only.

When $X = Y = 0$ and $X = -1, Y = 0$

26. Constant M circle equation is

$$y^2 + \left(x + \frac{M^2}{M^2 - 1} \right)^2 = \frac{M^2}{(M^2 - 1)^2}$$

Given equations is

$$8x^2 + 18x + 8y^2 + 9 = 0$$

Convert this equation in form of standard M -circle equation form

$$x^2 + \frac{9}{4}x + y^2 = \frac{-9}{8}$$

$$\left(x + \frac{9}{8} \right)^2 + y^2 = \frac{-9}{8} + \frac{81}{64} = \frac{-72 + 81}{64}$$

Comparing with standard equation

$$\frac{9}{8} = \frac{M^2}{M^2 - 1}$$

$$\text{or } 9M^2 - 9 = 8M^2$$

$$\text{or } M^2 = 9, M = \pm 3$$

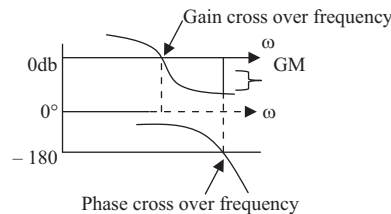
$$|M| = 3$$

27. The maximum phase added by phase-lead compen-sator for given network is given

$$\text{by Sin } \phi_m = \frac{a-1}{a+1}$$

28. For stable system

Gain at phase cross-over frequency will be always < 0 db



* Gain margin is the gain by which a system can be increased till system is stable.

29. Peak time for 2nd order system is given by

$$t_p = \frac{n\pi}{\omega_d} = \frac{n\pi}{\omega_n \sqrt{1-\delta^2}}$$

Second peak accure at $n = 3$

$$\therefore t_p = \frac{3\pi}{\omega_n \sqrt{1-\delta^2}}$$

$$30. R(s) = \frac{1}{s^2}$$

$$G(s) = \frac{1}{s(s+1)}$$

$$e_{ss} = \lim_{s \rightarrow 0} \frac{s \cdot R(s)}{1+GH} = \lim_{s \rightarrow 0} \frac{s \times \frac{1}{s^2}}{1 + \frac{1}{s(s+1)}}$$

$$= \lim_{s \rightarrow 0} \frac{s+1}{s^2+s+1} = 1$$

31. Unity feed back system

$$G(s) = \frac{K}{(s+2)(s+4)(s^2+6s+25)}$$

Characteristic equation $1+GH = 0$

$$1 + \frac{K}{(s+2)(s+4)(s^2+6s+25)} = 0$$

$$\text{or } (s+2)(s+4)(s^2+6s+25) + K = 0$$

$$\text{or } (s^2+6s+8)(s^2+6s+25) + K = 0$$

$$\text{or } s^4 + 12s^3 + 69s^2 + 198s + 200 + K$$

Apply RH Criterion

s^4	1	69	200 + K
s^3	12	198	
s^2	105/2	200 + K	
s^1	$\frac{105 \times 99 - (2400 + 12K)}{105/2}$	0	
s^0	200 + K		

For stability

$$8995 - 12K \geq 0 \Rightarrow 750 \geq K$$

and $-200 \geq K$

i.e., approximate value of $K = 790$

32. $c(t) = 1 - e^{-t} - t e^{-t}$

$$\begin{aligned} c(t) &= \frac{1}{s} - \frac{1}{s+1} - \frac{1}{(s+1)^2} \\ &= \frac{s^2 + 2s + 1 - s^2 - s - s}{s(s+1)^2} \\ &= \frac{1}{s(s^2 + 2s + 1)} \end{aligned}$$

$$H(s) = \frac{1}{s^2 + 2s + 1} = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

$$\omega_n = 1$$

$$\delta = \frac{2}{2} = 1; \text{ therefore, critically stable.}$$

33. $K = 2$ and $\omega = 1$ r/s

The characteristic equation is given as

$$s^4 + 2s^3 + 3s^2 + 25 + K = 0$$

Apply RH criterion

s^4	1	3	K
s^3	2	2	0
s^2	2	K	
s^1	$2 - K$		0
s^0	K		

For system to be stable

$$K \geq 0 ; 2 - K > 0 \Rightarrow 2 \geq K$$

Then, $2 \geq K \geq 0$

Therefore, at $K = 2$

Auxiliary equation

$$2s^2 + K = 0 \Rightarrow 2s^2 + 2 = 0$$

$$s^2 = -1 \Rightarrow s = \pm j$$

i.e., $\omega = 1$ rad/s

34. Characteristic equation

$$s^5 + 15s^4 + 85s^3 + 225s^2 + 274s + 120 = 0$$

$$1 + GH = 0 ; = 0$$

$$GH = \frac{120}{s(s^4 + 15s^3 + 85s^2 + 225s + 274)}$$

If $s = 0$

$$\text{Then } s^4 + 15s^3 + 85s^2 + 225s + 270 = 274$$

If $s = -1$ Then

$$1 - 15 + 85 - 225 + 270 = 86 + 270 - 240 = 356 - 240 = 116$$

It indicate all the roots are left hand side beyond $s = -1$

i.e., 4 roots lie to the left of line $s + 1 = 0$.

35. The tooth on all rotors are perfectly aligned, stator, tooth if various stacks differ by an displacement if $\alpha = 360^\circ/nT$

Where n = no. of stacks

Here n is not given, so we assume, 1 stack stepper motor with rotor in such a position that stack c rotor tooth are aligned with its stator

T = (number of rotor tooth = 12)

$$\alpha = \frac{360^\circ}{12} = 30^\circ$$

36. Routh-Array is formed

s^3	8	3	0
s^2	3	K	0
s^1	$\frac{9-8K}{3}$	0	
s^0	$\left(\frac{9-8K}{3}\right) K=0$		
	$\frac{9-8K}{3}$	0	
	$= K$	0	

For finding this characteristic equation is stable or not, we have equating the (S1) first subsidiary eq^n , with zero.

$$\frac{9-8K}{3} \geq 0$$

$$9-8K \geq 0$$

$$8K \leq 9$$

$$K \leq (9/8)$$

$$\Rightarrow 1.125,$$

So, in the option we have the value if K is less than 1.125 is zero.

37. The impedance,

$$Z(s) = 2s + 1/3s$$

is a inductance is series with capacitor because the Laplace transform of $2H$ is $2s$ and Laplace transform of $1/3F$ is $1/3s$.

38. In this RH. Criteria their are two sign changes in the elements of first column. So the two roots lie on the RHS of s plane. Then the system is unstable.

s^4	2	3	10
s^3	1	5	0
s^2	$\frac{3-10}{1}$	$\frac{10-0}{1}$	0
	$= -7$	10	
s^1	$\frac{-35-10}{-7}$	$\frac{0-0}{0}$	
	$= \frac{-45}{-7}$	0	
s^0	$\frac{45 \times 10}{7}$	0	
	$45/7 = 10$		

39. Because $= Mp = e^{[-\pi\delta/\sqrt{(1-\delta^2)}]} \times 100\%$

When $\delta = 0$

δ = damping coefficient

$$Mp = e^{-(0.0)} \times 100\%$$

$$Mp = 100\%$$

$$41. G(s)H(s) = \frac{1}{s(s+0.5)(s+1)}$$

$$G(j\omega)H(j\omega) = \frac{1}{j\omega(j\omega+0.5)(j\omega+1)}$$

$$\phi = \angle G(j\omega)H(j\omega)$$

$$= -90^\circ - \tan^{-1}2\omega - \tan^{-1}\omega$$

At phase crossover point $\phi = -180^\circ$

$$\therefore \tan^{-1}\omega + \tan^{-1}2\omega = 90^\circ$$

$$\Rightarrow \tan^{-1}\left(\frac{\omega+2\omega}{1-2\omega^2}\right) = 90^\circ$$

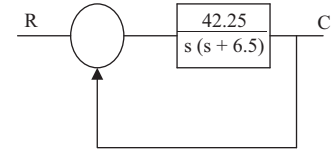
$$\frac{3\omega}{1-2\omega^2} = \infty$$

$$\Rightarrow 1-2\omega^2 = 0$$

$$\text{or } 2\omega^2 = 1$$

$$\therefore \omega = 0.707 \text{ rad/s.}$$

42.



$$\begin{aligned} \frac{C}{R} &= \frac{G(s)}{1+G(s)} = \frac{\frac{42.25}{s^2+6.5s}}{1+\frac{42.25}{s^2+6.5s}} \\ &= \frac{42.25}{s^2+6.5s+42.25} \\ &= \frac{\omega_n^2}{s^2+2\delta\omega_n s + \omega_n^2} \end{aligned}$$

$$\text{Then, } \omega_n^2 = 42.5 \Rightarrow \omega_n = 6.5$$

$$2\delta \times 6.5 = 6.5$$

$$\delta = (1/2) = 0.5$$

Unit step represent, at time with max value.

$$\begin{aligned} t_{\text{peak}} &= \frac{\pi}{\omega_n \sqrt{(1-\delta^2)}} = \frac{\pi}{6.5 \sqrt{[1-(0.5)^2]}} \\ &= \frac{\pi}{6.5 \sqrt{(1-0.25)}} = \frac{\pi}{6.5 \sqrt{(0.75)}} \\ &= \frac{\pi}{(6.5)(0.866)} \\ &= \frac{\pi}{5.63} = 0.558 \text{ sec} \end{aligned}$$

43. The characteristic equation is

$$s^2 + 0.2s + 1 = 0$$

When expressed in the form $s^2 + 2\delta\omega_n s + \omega_n^2$, we have

$$\omega_n = 1 \text{ and } \delta = 0.1$$

For a step input it is required that the response settles to within 2% of its final value. The plant setting time is given by the formula. Settling time

$$t_s = 4/\delta\omega_n = 4/(0.1 \times 1) = 40 \text{ sec.}$$

$$44. G_c(s) = \frac{1+6s}{1+2s}$$

Phase shift is $\phi = \tan^{-1}6\omega - \tan^{-1}2\omega$

$$\frac{d\phi}{d\omega} = \frac{6}{1+36\omega^2} - \frac{2}{1+4\omega^2}$$

For maximum value of ϕ , $\frac{d\phi}{d\omega} = 0$

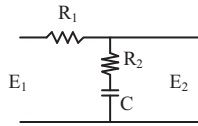
$$\therefore 3(1+4\omega^2) = 1+36\omega^2$$

$$\Rightarrow 24\omega^2 = 2$$

$$\text{or } \omega = 1/\sqrt{12} = (1/\sqrt{6}) (1/\sqrt{2})$$

$$\begin{aligned} \therefore \phi &= \tan^{-1} \sqrt{(36/12)} - \tan^{-1} \sqrt{(4/12)} \\ &= \tan^{-1} \sqrt{3} - \tan^{-1} 1/\sqrt{3} \\ &= 30^\circ \end{aligned}$$

45. Phase lag network/Compensator



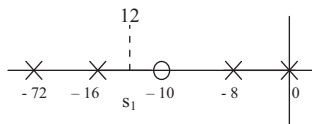
$$\frac{E_2(s)}{E_1(s)} = \frac{1 + R_2CS}{1 + (R_1 + R_2)S} = \frac{1 + aTS}{1 + TS}$$

$$\text{where } a = \frac{R_2}{R_1 + R_2} \quad (\therefore a < 1)$$

$$T = (R_1 + R_2)C$$

46. Value of K at any point s_1 , on the root Locus is given by

$$|K| = \frac{\text{Product of length vector drawn from poles to } s_1}{\text{Product of length vector drawn from zero to } s_1}$$



$$\frac{4 \times 4 \times 60 \times 12}{2} = \frac{960 \times 12}{2} = 480 \times 12$$

$$K = 5760$$

47. Compare the given equation result with standard second order unit response.

$$c(t) = \frac{1 - e^{-\delta\omega_n t}}{\sqrt{1 - \delta^2}} \sin \left[\left(\omega_n \sqrt{1 - \delta^2} \right) t + \theta \right]$$

$$c(t) = \frac{1 - e^{-\delta\omega_n t}}{\sqrt{1 - \delta^2}} \sin \left[\left(\omega_n \sqrt{1 - \delta^2} \right) t + \theta \right]$$

$$\text{We get } \delta\omega_n = 4$$

$$\text{Setting time (for 5\%)} = (3/\delta\omega_n) = (3/4) \text{ second.}$$

48. The given function is

$$T(s) = \frac{4}{s^2 + 2s + 4} = \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

$$\omega_n = 2; \delta\omega_n = 1$$

$$\therefore \delta = 0.5$$

Fractional maximum overshoot is

$$M_p = \exp \left[-\pi\delta/\sqrt{1 - \delta^2} \right] = \exp \left[-\pi \times 0.5/\sqrt{(0.75)} \right] = 0.163$$

$$\text{The maximum value is } 1 + 0.163 = 1.163 = (2/\sqrt{3}).$$

49. If $R \gg X$, The circuit is linear. Torque speed characteristic is linear for $(X/R) \ll 1$.50. Reference is made to, the isocline method (under **phase plane method**) for the analysis of non-linear system

$$\text{Let } x_1 = x$$

$$x_2 = \dot{x}_1 - \dot{x}$$

$$\therefore \frac{dx_2}{dx_1} = m = \frac{-ax\dot{x} - bx}{\dot{x}}$$

$$\Rightarrow m = -ax - \frac{bx}{\dot{x}}$$

$$51. G(j\omega) = \frac{j\omega}{1 + j\omega}$$

For $\omega = 0$, Lower order terms of ω is considered

For $\omega = \infty$, higher order terms of ω is considered

$$\text{At } \omega = 0; G(\omega) = \frac{j\omega}{1} \angle G(j\omega) = 90^\circ$$

$$\text{At } \omega = \infty; G(\omega) = \frac{j\omega}{j\omega}; \angle G(j\omega) = 0^\circ$$

52. Slope for pole $= -20 \times 14 = -280$ db/decade

Slope for zero $= 20 \times 2 = 40$ db/decade

Final slope $= -20 \times 12 = -240$ dB/decade corresponding to highest frequency asymptotes

53. Characteristic is $= 1 + GH = 0$

$$K = -(s^3 + 3s^2 + 6s)$$

$$\frac{dK}{ds} = 0,$$

$$3s^2 + 6s + 6 = 0$$

$$s^2 + 2s + 2 = 0$$

$$s = \frac{-2 \pm \sqrt{2^2 - 4 \cdot 1 \cdot 2}}{2} = \frac{-2 \pm \sqrt{4 - 8}}{2} = -1 \pm j1$$

54. $s = -a \pm jb$

Then characteristics is

$$(s + a + jb)(s + a - jb)$$

$$= s^2 + sa - jsb + sa + a^2 - jab + jsb + jab + b^2$$

$$= s^2 + 2as + a^2 + b^2 \quad (1)$$

$$\text{Stranded 2nd order characteristic equation is } s^2 + 2\delta\omega_n s + \omega_n^2 \quad (2)$$

Comparing equation (1) and (2)

$$\omega_n^2 = a^2 + b^2$$

$$\omega_n = \sqrt{a^2 + b^2}$$

$$2a = 2\delta\omega_n$$

$$\delta = \frac{a}{\omega_n} = \frac{a}{\sqrt{a^2 + b^2}}$$

55.

Type	K_p	K_v	K_a	$e_{ss} = R/1 + K_p$	$e_{ss} = R/K_v$	$e_{ss} = R/K_a$
0	K	0	0	$R/1 + K_p$	∞	∞
1	∞	K	0	0	R/K_v	∞
2	∞	∞	K	0	0	R/K_a
3	∞	∞	∞	0	0	0

Second Method

$$E(s) = R(s) \left[1 - \frac{C(s)}{R(s)} \right]$$

$$R(s) = \frac{1}{s} + \frac{1}{s^2} + \frac{1}{s^3}$$

$$\frac{C(s)}{R(s)} = \frac{10(1 + 4s)}{s^3 + s^2 + 40s + 10}$$

$$e_{ss} = \lim_{s \rightarrow 0} (s \cdot E(s)) = \infty$$

$$56. X(s) = \frac{1}{s(s+1)^3(s+2)}$$

Residue at the pole ($s=0$) is $s \cdot X(s)|_{s=0} = 1/2$

$$s \cdot X(s)|_{s=0} = \frac{s \cdot 1}{s(s+1)^3(s+2)} \Big|_{s=0} = \frac{1}{1 \times 2} = \frac{1}{2}$$

Residue at the pole

($s=-2$) is

$$(s+2) \cdot X(s)|_{s=-2} = \frac{(s+2) \cdot 1}{s(s+1)^3(s+2)} \Big|_{s=-2} = \frac{1}{(-2)(-2+1)^3} = -\frac{1}{2} \times \frac{1}{(-1)} = \frac{1}{2}$$

57. Characteristic equation from state space system given by

$$|sI - A| = 0$$

$$|sI - A| = s^2 - 4 = 0$$

$$s = \pm 2$$

58. $\phi(t) = LT^{-1} [sI - A]^{-1}$

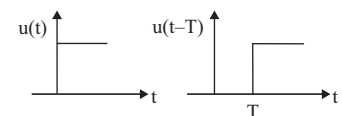
$$= \frac{Adj(sI - A)}{|sI - A|}$$

The eigen value of the system given by the roots of the characteristic equation i.e., $|sI - A| = 0$

$$s^2 + 6s + 5 = 0$$

$$s = -1 \text{ and } -5$$

59. Lag function means delay function



$u(t-T)$ is lag function it start at $t=T$. Which should be started at $t=0$. It is delayed by T sec.

$$u(t-T) \xrightarrow{LT} e^{-sT}$$

$$\begin{aligned}
 60. \quad G(s) &= \frac{s+5}{s^2+4s+9} \\
 s &= \frac{-4 \pm \sqrt{4^2 - 4 \cdot 1 \cdot 9}}{2} \\
 &= \frac{-4 \pm \sqrt{16-36}}{2 \cdot 1} = \frac{-4 \pm \sqrt{-20}}{2} \\
 &= 2 \pm j2\sqrt{5} \\
 \angle G(s) &= \frac{\tan^{-1}(0/5)}{\tan^{-1}\left(\frac{2\sqrt{5}}{2}\right)} \equiv \frac{\angle 90^\circ}{\angle 180^\circ} \\
 &\approx \angle 90^\circ - \angle 180^\circ = \angle -90^\circ \\
 &= 0 \text{ to } -90^\circ
 \end{aligned}$$

$$\begin{aligned}
 61. \quad 4 \frac{d^2 c(t)}{dt^2} + 8 \frac{dc(t)}{dt} + 16 c(t) &= 16 u(t) \\
 \text{Take Laplace transform} \\
 4s^2 C(s) + 8s C(s) + 16 C(s) &= 16 U(s) \\
 \frac{C(s)}{U(s)} = H(s) &= \frac{16}{4s^2 + 8s + 16} \\
 &= \frac{4}{s^2 + 2s + 4}
 \end{aligned}$$

Standard 2nd order system

$$\begin{aligned}
 \frac{\omega_n^2}{s^2 + 2\delta\omega_n + \omega_n^2} \\
 \text{Compare above two function} \\
 \text{Natural frequency } \omega_n = \sqrt{4} = 2 \\
 2\delta\omega_n = 2
 \end{aligned}$$

$$\text{Damping ratio } \delta = \frac{2}{2 \times 2} = 0.50$$

$$\begin{aligned}
 62. \quad \text{Given characteristic equation is} \\
 s^3 + 5s^2 + (K+6)s + K = 0
 \end{aligned}$$

$$\Rightarrow 1 + \frac{(s+1)K}{s(s+3)(s+2)} = 0$$

$$\Rightarrow 1 + G(s)H(s) = 0$$

The open-loop transfer function

$$G(s)H(s) = \frac{(s+1)}{s(s+3)(s+2)}$$

Intersection of asymptotes with real axis

$$\begin{aligned}
 \sigma &= \frac{\sum \text{Finite Poles} - \sum \text{Finite Zero}}{|P-Z|} \\
 &= \frac{[(-2) + (-3) + (0)] - (-1)}{3-1} \\
 &= \frac{-5+1}{2} = -2
 \end{aligned}$$

$$63. \quad GM = \frac{1}{|a|} = \frac{1}{0.4} = 2.5$$

$$\begin{aligned}
 64. \quad G_c(s) &= \frac{1+aTs}{1+Ts} \\
 \phi &= \tan^{-1} \omega Ta - \tan^{-1} \omega T \\
 \text{For maximum } \phi \\
 \frac{d\phi}{dT} &= 0 = \frac{\omega a}{1+(\omega Ta)^2} - \frac{\omega T}{1+(\omega T)^2} \\
 \omega a(1+\omega^2 T^2) &= \omega(1+\omega^2 T^2 a^2) \\
 \omega a + \omega^3 T^2 a &= \omega + \omega^3 T^2 a^2 \\
 \text{or } \omega^3 T^2 a - \omega^3 + T^2 a^2 &= \omega - \omega a \\
 \text{or } \omega^3 T^2 a(1-a) &= \omega(1-a) = \omega - \omega a \\
 \text{or } \omega^2 T^2 a &= 1 \\
 \omega T &= \frac{1}{\sqrt{a}}
 \end{aligned}$$

$$\begin{aligned}
 \Rightarrow \phi_m &= \tan^{-1} \left[\frac{\sqrt{a} - \frac{1}{\sqrt{a}}}{1 + \sqrt{a} \cdot \frac{1}{\sqrt{a}}} \right] \\
 &= \tan^{-1} \frac{a-1}{2\sqrt{a}} = \sin^{-1} \frac{a-1}{a+1}
 \end{aligned}$$

65. State-space Dynamic equation

$$x'(t) = A x(t) + B r(t)$$

$$c(t) = D x(t) + E r(t)$$

Then

$$A = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & -3 \end{bmatrix} \text{ and } B = \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix}$$

If a system is controllable then

$$[B \ AB] \neq 0$$

Now Test the system

$$\begin{aligned}
 AB &= \begin{bmatrix} -1 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & -3 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix} \\
 &= \begin{bmatrix} (-1 \times 1) + (0 \times 1) + (0 \times 0) \\ (0 \times 1) + (-2 \times 1) + (0 \times 0) \\ (0 \times 1) + (0 \times 1) + (-3 \times 0) \end{bmatrix} \\
 &= \begin{bmatrix} -1+0+0 \\ 0+(-2)+0 \\ 0+0+0 \end{bmatrix} \\
 &= \begin{bmatrix} -1 \\ -2 \\ 0 \end{bmatrix}
 \end{aligned}$$

$$[B \ AB] = \begin{bmatrix} 1 & -1 \\ 1 & -2 \\ 0 & 0 \end{bmatrix} = 0$$

Hence system is not controllable

For system to be observable the requirement is

$$\begin{aligned}
 \left| \frac{D}{DA} \right| &\neq 0 \\
 DA &= [1 \ 0 \ 2]_{1 \times 3} \begin{bmatrix} -1 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & -3 \end{bmatrix}_{3 \times 3} \\
 &= \begin{bmatrix} (-1+0+0) & (1 \times 0 + 0 \times -2 + 0) \\ (1 \times 0 + 0 + 2 \times 3) \end{bmatrix} \\
 &= [-1 \ 0 \ 6]
 \end{aligned}$$

$$\left| \frac{D}{DA} \right| = \begin{vmatrix} 1 & 0 & 2 \\ -1 & 0 & -6 \end{vmatrix} = 0$$

Hence system is not observable

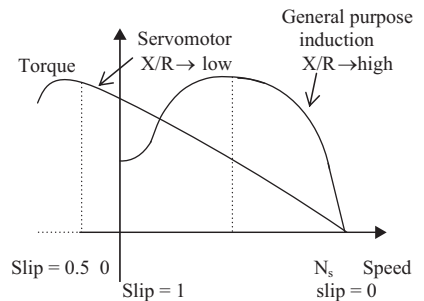
$$\begin{aligned}
 66. \quad \frac{Y(s)}{U(s)} &= G(s) = D[SI - A]^{-1} B \\
 &= \frac{[2 \ 0] \begin{bmatrix} s+3 & +1 \\ -2 & s \end{bmatrix} \cdot \begin{bmatrix} 0 \end{bmatrix}}{s(s+3)+2} = \frac{2}{s^2+3s+2}
 \end{aligned}$$

$$67. \quad C(s) = \frac{1}{(s+1)^2}$$

$$R(s) = \frac{1}{s}$$

$$H(s) = \frac{C(s)}{R(s)} = \frac{s}{(s+1)^2}$$

68. Torque speed characteristic of AC servomotor:



Torque speed characteristic of AC servomotor

R → resistance of rotor

X → Inductance of rotor

Difference between general purpose Induction motor and AC servomotor:

$$1. \quad \left(\frac{X}{R} \right)_{\text{servomotor}} < \left(\frac{X}{R} \right)_{\text{General purpose induction motor}}$$

2. Torque speed characteristics is linear for A.C. servomotor whereas it is non-linear for general purpose induction motor.

69. The definition of stability for discrete time linear system is the same as its continuous counterpart. A stable discrete system should return to its equilibrium

point (may be taken as the origin) following any transient disturbance.

It can be shown that the transient response of a linear n th order discrete systems contain terms involving λ_j^k (for $j=1, 2, \dots, n$) at the k th sampling instant, where λ_j 's are the pole of the pulse transfer function of the system. Thus the system will be stable if for all the poles the following strict inequality is satisfied,

$$|\lambda_j| < 1 \quad (i=1, 2, \dots, n) \quad (9.4-13)$$

As λ_j is generally complex, the inequality (9.4-13) implies that all the poles lie within the unit circle in the z -plane, with the origin as the centre, for stability. The origin as the centre, for stability. This is illustrated in figure 9.4-4

The attempt to apply the algebraic methods directly in this case will meet the obvious difficulty that the zone of stability lies inside the unit circle. The conventional Routh test determines whether any root of the characteristic polynomial lies to the right half of the s -plane. To eliminate this difficulty we take the help of bilinear transformation.

$$z = \frac{r+1}{r-1}$$

It can be very easily shown that a unit circle in the complex z -plane, and all points belonging to the exterior of the unit circle in the z -plane is mapped onto the left half of the r -plane. Thus the Routh algorithm may be used on the polynomial obtained after setting.

$$z = \frac{r+1}{r-1}$$

In the characteristic equation $f(z) = 0$ and simplifying it.

70. Characteristic equation for discrete data system is given by

$$|zI - A| = 0$$

$$\Rightarrow \begin{vmatrix} z & -1 \\ 3 & z+5 \end{vmatrix} = 0$$

$$\Rightarrow z^2 + 5z + 3 = 0$$

$$71. G(s) = \frac{121}{s^2 + 13.2s + 121}$$

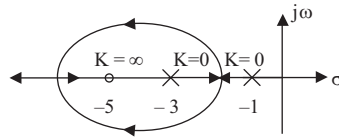
$$= \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2}$$

$$\omega_n = \sqrt{121} = 11 \text{ rad/s}, 2\delta\omega_n = 13.2$$

$$\Rightarrow \delta = 0.6 \quad (<1, \text{ under damped})$$

$$\therefore T_s = \frac{4}{\delta\omega_n} = 0.606s \text{ (for 2 \% errors)}$$

72.



$$\begin{aligned} \text{Number of asymptotes} &= P - 3 \\ &= 3 - 1 = 2 \end{aligned}$$

RL intersect the real axis at two points as break away point and break in point

73. Apply RH Criterion

Construction rough array.

$$\begin{array}{c|cc} s^4 & 3 & 5 \\ s^3 & 10 & 2 \\ s^2 & 4.4 & 0 \\ s^0 & 2 & \end{array}$$

cash term of the first column is +ve, therefore system is stable

$$74. \phi = \tan^{-1} \omega - \tan^{-1} \frac{\omega}{2}$$

For any frequency ω , $\phi > 0$ and hence transfer function represents phase lead compensator.

In phase lead compensator, zero is nearer to origin than pole.

$$75. Q_o = [B \quad BA]$$

$$= \begin{bmatrix} 0 & 1 \\ 1 & -3 \end{bmatrix}$$

$\det Q_o \neq 0$ [System is controllable]

$$Q_o = [C^T \quad A^T C^T]$$

$$C^T = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

$$A^T C^T = \begin{bmatrix} 0 & -2 \\ 1 & -3 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} -2 \\ -2 \end{bmatrix}$$

$$Q_o = \begin{bmatrix} 1 & -2 \\ 1 & -2 \end{bmatrix}$$

and $\det Q = 0 \Rightarrow$ [unobservable]

LEVEL 3

1. The characteristic equation is

$$s^2 + (3 - K)s + 1 = 0$$

At $K = 0$,

$$s^2 + 3s + 1 = 0$$

$$s = \frac{-3 \pm \sqrt{9 - 4}}{2} = \frac{-3 \pm \sqrt{5}}{2} = -2.62, -0.38$$

These are the poles of $KG(s)$ since the root locus stands at the poles of $KG(s)$.

At $K = 1$,

$$s^2 + 2s + 1 = 0 \text{ or } (s + 1)^2 = 0$$

$$s = -1$$

i.e., meeting of 2 branches or root locus is at $s = -1$

At $K = 3$, we have $s^2 + 1 = 0$, $s = \pm j$

At $K = \infty$,

$$\lim_{K \rightarrow \infty} s^2 + (3 - K)s + 1 = 0$$

$$\lim_{K \rightarrow \infty} \frac{s^2}{K} + \frac{3s}{K} - s + \frac{1}{K} = 0 \text{ or } s = 0$$

i.e., a zero exists at $s = 0$

Hence, satisfying all these conditions, choice (b) is correct

2. Masson's gain formula, $[C/R] = [\Sigma P_R \Delta_R / \Delta]$

Forward path 1 Gain $P_1 = 1$. 2. 3. 4 = 24

Forward path 3 Gain $P_2 = 1.5 = 5$

$$\Delta_1 = 1$$

$$\Delta_2 = 1 - (3 \times -1)$$

$$= 1 + 3 = 4$$

Gains of Loop 1	-2
Gains of Loop 2	-3
Gains of Loop 3	-4
Gains of Loop 4	-5

Non touching loop gain = $(-2)(-4) = 8$

$$\Delta = 1 - (-2 - 3 - 5 - 4) + 8$$

$$= 1 + 14 + 8 = 23$$

$$\Sigma P_R \Delta_R = P_1 \Delta_1 + P_2 \Delta_2 = 24 \times 1 + 5 \times 4 = 24 + 20 = 44$$

$$\begin{aligned} [C/R] &= [\Sigma P_R \Delta_R / \Delta] \\ &= [44 / 23] \end{aligned}$$

3. F.P. Gain $M = 5 \cdot 2 \cdot 1 = 10$

$$\text{Loop gain} = -4 \quad \Delta = 1 - [-4] = 5$$

$$\begin{aligned} [C/R] &= \frac{10 \cdot 1}{5} = \sum \frac{M_i \Delta_i}{\Delta} \\ &= 2 \end{aligned}$$

4. The value of k which lie left of $j\omega$ axis makes system stable if these value lie within the close circle then system becomes over damped, the value of over damped is $0 \leq k < 1$ or $k > 5$

Method Second

Characteristic equation:

$$1 + GH = 0$$

$$\Rightarrow 1 + \frac{K(s+3)}{(s+1)(s+2)} = 0$$

$$\Rightarrow s^2 + 3s + 2 + Ks + 3K = 0$$

$$\Rightarrow s^2 + (3 + K)s + (2 + 3K) = 0$$

Standard second order characteristic equation

$$s^2 + 2\delta\omega_n s + \omega_n^2 = 0$$

Comparing the above two equation, we get

$$\omega_n = \sqrt{(2+3K)}$$

$$2\delta\omega_n = (3+K)$$

$$\delta = \frac{(3+K)}{2(2+3K)}$$

For stability, $\delta > 1$

$$\Rightarrow \frac{(3+K)}{2\sqrt{(2+3K)}} > 1$$

$$\Rightarrow 9 + K^2 + 6K > 4(2+3K)$$

$$9 + K^2 + 6K - 12K - 8 > 0$$

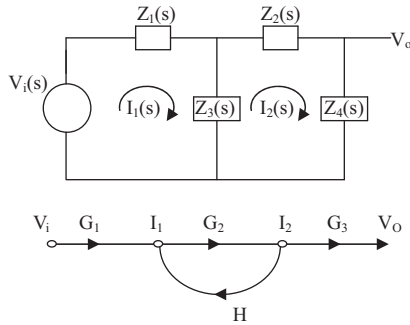
$$K^2 - 6K + 1 > 0$$

$$K = \frac{6 \pm \sqrt{(36-4)}}{2}$$

$$K = 5.82 \text{ \& } 0.17$$

Which satisfy the condition (d)

5.



KVL in loop 1

$$V_i(s) = Z_1(s)I_1(s) + Z_3(s)[I_1(s) - I_2(s)]$$

$$V_i(s) + Z_3(s)I_2(s) = I_1(s)[Z_1 + Z_3]$$

$$I_1 = \frac{V_i(s)}{Z_1 + Z_2} + \frac{I_1 Z_2}{Z_1 + Z_3} \quad (1)$$

From signal Flow graph

$$I_1 = V_i G_1 + I_2 H \quad (2)$$

Comparing equation (1) and (2)

$$H = \frac{Z_2}{Z_1 + Z_2}$$

KVL in loop 2

$$[I_2(s) - I_1(s)]Z_3(s) + I_2(s)Z_2(s) + I_2(s)Z_4(s) = 0$$

$$I_2(s)[Z_2 + Z_3 + Z_4] = I_1 Z_3$$

$$G_2 = \frac{I_2}{I_1} = \frac{Z_3}{Z_2 + Z_3 + Z_4}$$

6. The encirclement of critical point $(-1, j0)$ is once in anticlockwise direction

$$\therefore N = 1$$

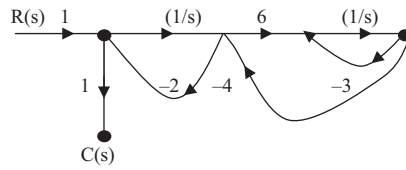
$G(s)H(s)$ has one right side pole

$$\therefore P = 1$$

$$Z = P - N = 1 - 1 = 0$$

No zero in the right hand side of s-plane
So system is stable.

7.



$$\text{Loop gain } I_1 = -[2/S]$$

$$I_2 = -[3/S]$$

$$I_3 = -[24/S]$$

Non-touching loops

$$[\text{loop}_1 \times \text{loop}_2] = -[2/S] \times [-3/S] = [6/S^2]$$

$$G(s) = \frac{C(s)}{R(s)} = \sum \frac{\Delta_k M_k}{\Delta}$$

$\Delta = 1 - (\text{Sum of loop gain}) + (\text{Product of two non-touching loop})$

$$= 1 - \frac{2}{S} - \frac{3}{S} - \frac{24}{S} + \frac{6}{S^2} = \frac{S^2 + 29S + 6}{S^2}$$

$$M_1 = 1$$

For path No touching = $1 + [3/S] + [24/S]$

$$= [(S+27)/S]$$

$$C(s) = \frac{M_1 \Delta_1}{\Delta} = 1 \times \frac{(S+27)/S}{\Delta}$$

$$= \frac{[(S+27)/S]}{\frac{S^2 + 29S + 6}{S^2}} = \frac{S(S+27)}{S^2 + 29S + 6}$$

9. $M_1 = KS^{-1}$

$$\Delta_1 = 1$$

$$\Delta = 1 - [KS^{-1} + 3S^{-1}]$$

$$C = \frac{K/S}{1 - \left(\frac{-K}{S} + \frac{3}{S}\right)}$$

$$R = \frac{K/S}{[S - (-K+3)/S]}$$

$$\frac{Y(s)}{R(s)} = \frac{K}{s-3+K}$$

The system will be unstable when, single pole for $K > 3$ lies in the RHS of plane, i.e.,

RH Table

$$\begin{array}{c|c} S^1 & S \\ S^0 & -3+K \end{array}$$

$$K - 3 > 0$$

$$\text{Or, } K > 3$$

10. From $\omega = 0.1$ to 10 , i.e., in two decade dB change is 120 dB i.e., 60 dB/decade which means there are 3 zeros at $\omega = 0.1$,

Now from $\omega = 10$ to $\omega = 100$, i.e., in one decade change is 20 dB/decade, it means decrease in 40 dB/decade which indicate 2 poles at $\omega = 10$. Like wise at $\omega = 100$, slope changes is constant i.e., decrease in 20 dB/decade. Which indicates one pole at $\omega = 100$.

$$\text{Thus, } G(s) = \frac{K(s+0.1)^3}{(s+10)^2(s+100)}$$

$$G(j\omega) = \frac{K(j\omega+0.1)^3}{(j\omega+10)^2(j\omega+100)}$$

At $\omega = 0$, gain is 20 db

$$\text{Hence } |G(j\omega)|_{\omega=0} = \frac{K(0+0.1)^3}{(0+10)^2(0+100)}$$

$$10 = \frac{K \times 10^{-3}}{10^2 \times 10^2}$$

$$K = \frac{10 \times 10^2 \times 10^2}{10^{-3}} = 10^5 \times 10^3 = 10^8$$

11. $2\delta\omega_n = 4$

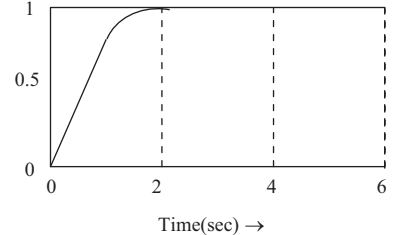
$$\delta\omega_n = 2$$

$$\text{and } \omega_n = 2$$

then, $\delta = 1$ (critically-damped system)

$$\text{and } t_{ss} (\text{Setting time}) = \frac{4}{\delta\omega_n} = 2 \text{ sec}$$

Step Response



Thus, only response is as shown in Figure (b).

Figure (d) is also critically-damped system, but its setting time is about 5 sec. Hence, the only choice is (b).

12. At $\omega = 1$, slope changes from 0 dB/decade to 20 dB/decade, and, at $\omega = 10$, slope changes from 20 dB/decade to 0 dB/decade and at $\omega = 100$, slope changes from 0 dB/decade to -20 dB/decade.

Hence, there is a zero at $\omega = 1$ and poles at $\omega = 10, 100$.

$$\text{Now, } G(s) = \frac{k(s+1)}{(s+10)(s+100)}$$

$$G(j\omega) = \frac{k(j\omega+1)}{(j\omega+10)(j\omega+100)}$$

$$= \frac{k(j\omega+1) \cdot 10^3}{(j\omega+1)(j\omega+100)}$$

Then, $20 \log (10^{-3} k) = -20$

Or, $k = 10^2$

Hence, $G(s) = \frac{10^2 (s+1)}{(s+10)(s+100)}$

Another way

$$20 \log_{10} |G(j\omega) H(j\omega)|_{\omega=0} = -20$$

$$20 \log_{10} 10^{-1} = -20$$

$$\therefore |G(j\omega) H(j\omega)|_{\omega=0} = (10)^{-1} = 0.1$$

$$T(0) = \frac{K(1)}{(10)(100)} = 0.1$$

$$\Rightarrow K = 10^2$$

13. Forward path gain, $P_1 = abcd$

And, as it touches all the three loops, $\Delta_1 = 1$.

Now, Three individual loops with loop gains

$$P_{11} = be, P_{21} = cf, P_{31} = dg$$

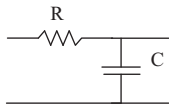
And combination of two non-touching loops with loop gains products,

$$P_{12} = bedg$$

$$\text{Then, } \frac{C}{R} = \frac{x_5}{x_1} = \frac{P_1 \Delta_1}{1 - (P_{11} + P_{21} + P_{31}) + P_{12}}$$

$$= \frac{abcd}{1 - (be + cf + dg) + be.dg}$$

14. Lag network is an RC network



$$G(s) = [1/(1 + sT)]$$

$$G(j\omega) = \frac{1}{1 + j\omega T}$$

$$= \frac{1}{(1 + j\omega T)} \angle -\tan^{-1} \omega T$$

$$= M \angle \phi$$

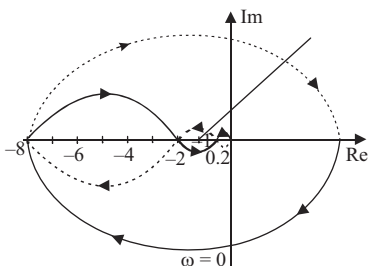
When $\omega = 0$, $M = 1$ and $\phi = 0$

The phasor at $\omega = 0$ has unit length & lies along the positive real axis. As ω increases M decreases & ϕ phase angle increases negatively.

When $\omega = [1/T]$, $M = [1/\sqrt{2}]$, $\phi = -45^\circ$

$\omega \rightarrow \infty$, $M \rightarrow 0$, $\phi = -90^\circ$

15. The closed loop system is stable for



System is stable in region -0.2 to -2 and on the left side of -8 as the number of encirclement is zero

$$0.2 K < 1$$

$$\Rightarrow K < 5$$

$$2K > 1$$

$$\Rightarrow K > 0.5$$

$$\therefore 0.5 < K < 5$$

$$\text{and } 8K < 1$$

$$K < \frac{1}{8}$$

16. The Rough sketch of the root locus is a circle

$$\{d/ds\} [G(s) H(s)] = 0;$$

The breakaway point is

$$\frac{-s(s+3) - (1-s)(2s+3)}{s(s+3)} = 0$$

$$S = 3 \text{ or } -1$$

17. Characteristic equation $1 + GH = 0$

$$= s^3 + as^3 + 2s + 1 + k(s+1) = 0$$

$$= s^3 + as^2 + (2+k)s + (1+k) = 0$$

Routh Hurwitz array

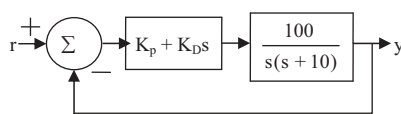
$$\begin{array}{c|cc} s^3 & 1 & 2+k \\ s^2 & a & 1+k \\ s^1 & \frac{(1+k) - a(2+k)}{a} & 0 \\ s^0 & 1+k & \end{array}$$

For oscillating at 2 rad/sec.

$$\frac{2+k}{1} = \frac{1+k}{a} = 2^2$$

$$\Rightarrow k = 2 \text{ and } a = 0.75$$

- 18.



Given that,

$$K_v = 1000, \quad \delta = 0.5$$

$$T(s) = \frac{100(K_p + K_D s)}{s^2 + (100K_D + 10)s + K_p 100}$$

$$1 + G(s)H(s) = s^2 + (100K_D + 10)s + 100K_p$$

$$\therefore \omega_n^2 = 100K_p$$

$$2\delta \omega_n = 2 \times 0.5 \omega_n = \omega_n = 100K_D + 10$$

$$\therefore \sqrt{K_p 100} = 100K_D + 10$$

$$\sqrt{K_p} = 10K_D + 1 \quad (1)$$

$$\text{Also } K_v = 1000$$

$$K_v = \lim_{s \rightarrow 0} sG(s)H(s)$$

$$1000 = \lim_{s \rightarrow 0} \frac{s 100 (K_p + sK_D)}{s(s+10)}$$

$$1000 = 10K_p$$

$$K_p = 100$$

From (1)

$$\sqrt{K_p} = 10K_D + 1$$

$$\Rightarrow 10K_D = \sqrt{100} - 1 = 9$$

$$K_D = 0.9$$

19. At $\omega = 0.1$ gain is 60 db that is due to K and $[1/s]$

$[1/s]$ give gain = 20 db at 0.1 and 40 db due to K

Therefore, $20 \log K = 40 \Rightarrow K = 100$

$$T_1 = \frac{1}{1}$$

$$T_2 = \frac{1}{20} = 0.05$$

$$G(s) = \frac{K}{s(1+sT_1)(1+sT_2)} = \frac{100}{s(1+s)(1+0.05s)}$$

Another way

$$G(s) = \frac{K}{s(s+1)(s+20)} = \frac{K}{s(s+1)20(1+0.05s)}$$

as there is slop in the beging of plot

$$G(s) = \frac{K/20}{s(s+1)\left(1+\frac{s}{20}\right)} = \frac{K'}{s(s+1)(1+0.5s)}$$

As the term are in the $(1+sT)$ form

$$20 \log \frac{K'}{\omega} \bigg|_{\omega=0.1} = 60 \text{ db}$$

$$= \frac{K'}{\omega} \bigg|_{\omega=0.1} = (10)^3$$

$$\text{or } \frac{K'}{0.1} = (10)^3$$

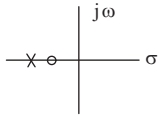
$$\text{or } K' = 100$$

$$G(s) = \frac{100}{s(s+1)(1+0.5s)}$$

20. Nyquist path $s = -j\infty$ ----- $+j\infty$ anti-clockwise

Total angle covered = 720° clock wise

27.



The transfer function of a phase-lead compensator is

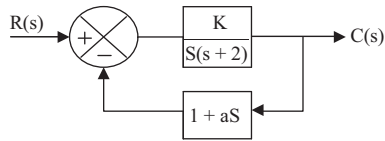
$$\frac{E_2(s)}{E_1(s)} = \frac{1(1+aTs)}{a(1+Ts)}, a > 1$$

Zero is at $s = -[1/aT]$

Pole is at $s = -[1/T]$

Hence choice (a) is correct, since $a > 1$

28. For feedback control system transfer function $T(s) = [G(s)/\{1 + G(s)H(s)\}]$



$$\frac{C(s)}{R(s)} = 1 + \frac{\frac{K}{s(s+2)}}{\frac{K}{s(s+2)}(1+as)}$$

$$= \frac{K}{s(s+2) + (1+as) + K}$$

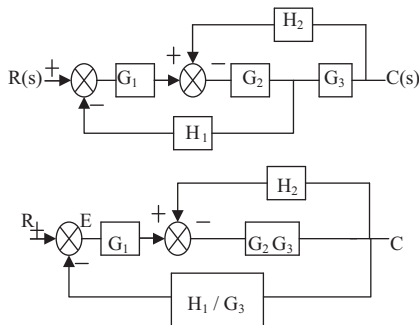
$$= \frac{K}{s^2 + s(2+Ka) + K}$$

$$K = \omega_n^2 = 16$$

$$2\delta\omega_n = 2 + Ka = 2 \times 0.7 \times 4 = 5.6$$

$$a = \frac{5.6 - 2}{16} = 0.225$$

29.



$$\frac{C}{E} = \frac{G_1 G_2 G_3}{1 + G_2 G_3 H_2}$$

$$\frac{C}{R} = \frac{\frac{G_1 G_2 G_3}{1 + G_2 G_3 H_2}}{1 + \left(\frac{G_1 G_2 G_3}{1 + G_2 G_3 H_2} \right) \times \frac{H_1}{G_3}}$$

$$= \frac{G_1 G_2 G_3}{1 + G_2 G_3 H_2 + G_1 G_2 H_1}$$

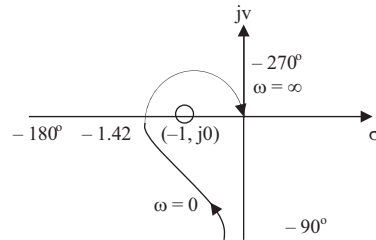
30. 6 db/octave = 20 db / dec

The Slope is +20 db / dec

is equal to placing a zero at f_1

$$A = 1 + \frac{jf}{f_1}$$

31.



$$a = +1.42$$

GM (gain margin) = $-20 \log a$

Since $a > 1$

So GM will be -ve and system unstable

$$a = +1.42$$

One pole is on origin, one poles as RHS and one pole on LHS.

32. Since at $\omega = 2$ and $\omega = 25$, slope changes from 40 dB to -60 dB/dec at both the value. So there are poles at $\omega = 2$ and $\omega = 25$. Also at $\omega = 0.1$ slope is -40 dB/sec. It means, there is two poles at origin. Hence the transfer function, should be of the form

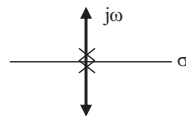
$$T(s) = \frac{K(s+5)}{s^2(s+2)(s+25)}$$

$$\text{Now, at } \omega = 0.1 \quad 54 = 20 \log \frac{5K}{(0.1)^2 \times 50}$$

$$\text{or} \quad K = 50$$

$$\text{thus} \quad T(s) = \frac{50(s+5)}{s^2(s+2)(s+25)}$$

33.



$$G(s) = [K/s^2]$$

Angle of asymptote,

$$\phi_A = \frac{\pm(2K+1)180}{2-0} = \pm 90$$

Hence root locus can be option (b)

$$34. e_{ss} = \lim_{s \rightarrow 0} \frac{s \cdot R(s)}{1 + G(s)H(s)} \text{ as } R(s) = \frac{1}{s}$$

$$= \lim_{s \rightarrow 0} \frac{s \times \frac{1}{s}}{1 + \left(\frac{3}{s+15} \right) \left(\frac{15}{s+1} \right)}$$

$$= \lim_{s \rightarrow 0} \frac{s^2 + 16s + 15}{s^2 + 16s + 60} = \frac{15}{60}$$

$$= \frac{1}{4} \times 100 = 25\%$$

35. Characteristic equation = $1 + G(s)H(s) = 0$

$$= s^2 + 16s + 60 = 0$$

$$s = \frac{-16 \pm \sqrt{16^2 - 240}}{2}$$

$$= \frac{-16 \pm 4}{2} = -6, -10$$

$$36. \angle GH|_{\omega=0.5a} = -\tan^{-1} \frac{\omega}{a}$$

$$= -\tan^{-1} 0.5 = 26.56^\circ$$

From the plot,

$$\text{At } \omega = a, \quad \angle GH = 22.5^\circ$$

$$\text{Then error} = -22.50^\circ - (-26.56^\circ) = 4.06^\circ$$

$$\text{At } \omega = 0.5a, |GH|_{dB} = 20 \log K - 20 \log |1 + j0.5|$$

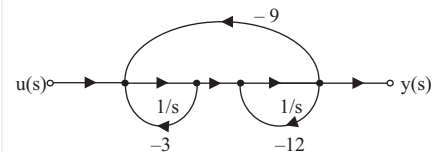
$$= 20 \log K - 0.97$$

$$\text{From the plot, at } \omega = 0.5a |GH|_{dB}$$

$$= 20 \log |GH| = 20 \log K$$

$$\text{Then, error in dB gain} = 0.97 \text{ dB}$$

37.



$$\text{Forward path gain, } P_1 = \frac{2}{s^2}$$

Individual loop gains

$$= \left(\frac{-3}{s} \right), \left(\frac{-12}{s} \right), \left(\frac{-18}{s^2} \right)$$

$$P_{12} \text{ (Non-touching loop gain)} = 36/s^2$$

$$\frac{Y(s)}{U(s)} = T(s) = \frac{P_1 \Delta_1}{1 - P_{11} - P_{21} - P_{23} + P_{12}}$$

$$= \frac{2/s^2}{1 + \frac{15}{s} + \frac{18}{s^2} + \frac{36}{s^2}}$$

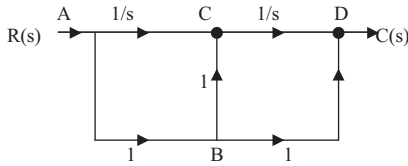
$$= \frac{2}{s^2 + 15s + 54}$$

$$= \frac{2}{(s+6)(s+9)}$$

$$= \frac{2}{(6 \times 9)} = \frac{2}{\{(s+6)(s+9)\}}$$

$$= \frac{1}{27 \left(1 + \frac{s}{6} \right) \left(1 + \frac{s}{9} \right)}$$

38. Constructing signal-flow graph as shown here,



Number of forward paths is 3 i.e., ACD, ABD, ABCD, having path gains,

$$P_1 = 1/s^2, P_2 = 1, P_3 = 1/s$$

There are no loops, then, transfer function is given by Masson's gain formula

$$T = \frac{P_1\Delta_1 + P_2\Delta_2 + P_3\Delta_3}{\Delta}$$

Where,

$$[\Delta_1 = \Delta_2 = \Delta_3 = \Delta = 1]$$

$$= \frac{1}{s^2} + 1 + \frac{1}{s} = \frac{s^2 + s + 1}{s^2}$$

$$\begin{aligned} 39. \quad T(s) &= \frac{C(s)}{R(s)} = \frac{k/s(s+2)}{1 + \frac{k(1+sP)}{s(s+2)}} \\ &= \frac{k}{s^2 + (2+Pk)s + k} \end{aligned} \quad (1)$$

Standard 2nd order equation

$$= \frac{\omega_n^2}{s^2 + 2\delta\omega_n s + \omega_n^2} \quad (2)$$

Compare equation (1) and (2)

Now, $k = \omega_n^2$, and $(Pk + 2) = 2\delta\omega_n$

Then, $k = 25$ and $25P + 2 = 2 \times 7 \times 5 = 7$

$25P = 5$

$P = 5/25 = 1/5 = 0.2$

$$\begin{aligned} 40. \quad H(s) &= \frac{s}{(s+1)} \\ \phi &= 90 - 45 = 45^\circ \\ |H(s)| &= \frac{1}{\sqrt{1+1}} = \frac{1}{\sqrt{2}} \end{aligned}$$

Therefore this transfer function circuit will give amplitude change of $1/\sqrt{2}$ and phase 45°

Hence, in steady state output is, $1/\sqrt{2} \sin(t + 45^\circ)$

Second Method

$$x(t) = \sin t, x(s) = \frac{1}{s^2 + 1}; Y(s)$$

$$= X(s) \frac{s}{s+1}$$

$$\begin{aligned} Y(s) &= \frac{1}{(s^2 + 1)} \cdot \frac{s}{s+1} \\ &= \frac{A}{(s+j)} + \frac{B}{(s-j)} + \frac{C}{(s+1)} \end{aligned}$$

$$\begin{aligned} &= \frac{1}{2(j)} \left(\frac{1}{s-j} \right) + \frac{1}{2(1-j)(s+j)} \\ &\quad - \frac{1}{2(s+1)} \end{aligned}$$

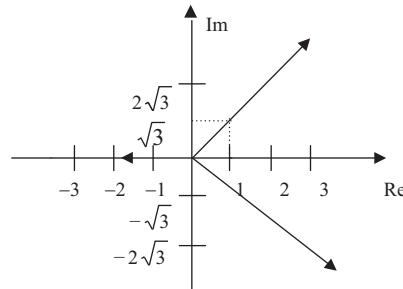
Taking inverse Laplace transformation, we have

$$\begin{aligned} y(t) &= \frac{1}{2(1+j)} e^{jt} + \frac{1}{2(1-j)} e^{-jt} - \frac{1}{2} e^{-t} \\ &= \frac{1}{2} (\sin t + \cos t) - \frac{1}{2} e^{-t} \\ &= \frac{1}{\sqrt{2}} \sin(t + 45^\circ) - \frac{1}{2} e^{-t} \end{aligned}$$

Then, steady state value = $\lim_{t \rightarrow \infty} y(t)$

$$\frac{1}{\sqrt{2}} \sin(t + 45^\circ)$$

41.



The given figure shows that all the roots are at origin or Root locus breaking point is at origin. Therefore the correct option is $k./s^3$.

$$G(s)H(s) = \frac{K}{s^3}$$

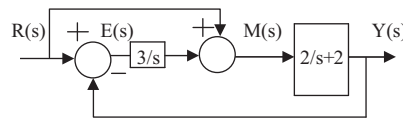
$$\frac{dK}{ds} = 0$$

$$3s^2 = 0$$

$$s = 0, 0$$

Thus breaking points are at origin.

42.



$$R(s) = 1/s$$

$$M(s) = R(s) + [R(s) - Y(s)] \frac{3}{s}$$

$$\text{And } Y(s) = \frac{2}{s+2} \left[R(s) \left(1 + \frac{3}{s} \right) - \frac{3}{s} Y(s) \right]$$

$$\text{or } Y(s) + \frac{6}{s(s+2)} Y(s)$$

$$= R(s) \frac{(s+3)}{s} \cdot \frac{2}{(s+2)}$$

$$\text{or } Y(s) \left[\frac{s(s+2)+6}{s(s+2)} \right] = R(s) \frac{2(s+3)}{s(s+2)}$$

$$\frac{Y(s)}{R(s)} = \frac{2(s+3)}{s(s+2)} \times \frac{s(s+2)}{s^2 + 2s + 6}$$

$$\therefore \frac{Y(s)}{R(s)} = \frac{2(s+3)}{s^2 + 2s + 6}$$

$$E(s) = R(s) - Y(s)$$

$$= R(s) \left[1 - \frac{2(s+3)}{s^2 + 2s + 6} \right]$$

$$E(s) = R(s) \frac{s^2}{s^2 + 2s + 6} = \frac{s}{s^2 + 2s + 6}$$

$$e_{ss} = \lim_{s \rightarrow 0} sE(s) = 0$$

43. Here, $G(s) = \frac{K + 0.366s}{s(s+1)}$, in present

case, unity feedback is applied

Since, Phase Margin = $180^\circ + \angle G(j\omega)$
 $H(j\omega)$

$$60^\circ = 180^\circ + \tan^{-1} \left(\frac{0.366\omega}{K} \right) - 90^\circ - \tan^{-1} \omega$$

$$\left[\tan^{-1} A - \tan^{-1} B = \tan^{-1} \left\{ \frac{A-B}{1+A \cdot B} \right\} \right]$$

$$\Rightarrow \tan^{-1} \left(\frac{0.366\omega}{K} - \omega \right) = -30^\circ$$

$$\Rightarrow \frac{0.366\omega - \omega K}{K + 0.366\omega^2} = -\frac{1}{\sqrt{3}}$$

Solving we get, $K + 0.366 = 1.732 k - 0.634$

$$\therefore k = 1.366$$

44. Given $H(j\omega) = \frac{10^4(1+j\omega)}{(10+j\omega)(100+j\omega)^2}$

Convert the given equation in standard form

$$\text{i.e., } \frac{K(1+j\omega T_1) \dots}{(j\omega)^n (1+j\omega T_a)(1+j\omega T_b)^2}$$

$$= \frac{10^4(1+j\omega)}{10 \left(1 + \frac{j\omega}{10} \right) (100)^2 \left(1 + \frac{j\omega}{100} \right)^2}$$

$$= \frac{0.1(1+j\omega)}{\left(1 + \frac{j\omega}{10} \right) \left(1 + \frac{j\omega}{100} \right)^2}$$

Value of $K_{db} = +20 \log_{10} (0.1) = -20 \text{ db}$.

So plot will start from -20 db ft.

In other way this problem can be seen as

When $\omega \rightarrow 0$

$$\text{Gain} \rightarrow H(0) = \frac{10^4}{10 \times 100} = 10$$

$$20 \log [1/10] = -20 \text{ dB}$$

Where, $A_3 = \frac{1}{s^2 + a_1s + a_o}$

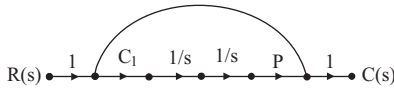
$X = C_o + C_1s$

$Y = \frac{1}{s^2 + a_1s + a_o}$

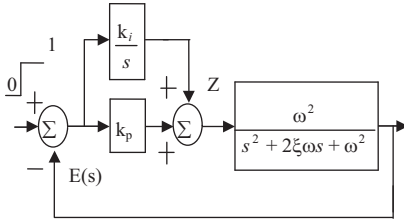
$Z = b_o + b_1s$

Another method

Transform the block diagram into signal flow graph, then use Masson's gain formula



50.



$E(s) = \frac{R(s)}{1 + G(s)H(s)}$

$r(t) \rightarrow$ Unit step

$R(s) \rightarrow (1/s)$

The steady state of z is

$z(\infty) = \lim_{s \rightarrow 0} s Z(s) = \lim_{s \rightarrow 0} s E(s) \frac{K_i}{s}$

$= \lim_{s \rightarrow 0} \frac{s \cdot \frac{K_i}{s}}{1 + \left(K_p + \frac{K_i}{s}\right) \left(\frac{\omega^2}{s^2 + 2s\omega_p s + \omega^2}\right)}$

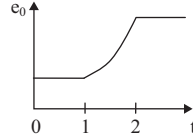
$= \lim_{s \rightarrow 0} \frac{\frac{K_i}{s}}{1 + \left(K_p + \frac{K_i}{s}\right) \left(\frac{\omega^2}{s^2 + 2s\omega_p s + \omega^2}\right)}$

$\lim_{s \rightarrow 0} \frac{K_i}{s \left(1 + \left(K_p + \frac{K_i}{s}\right) \left(\frac{\omega^2}{s^2 + 2s\omega_p s + \omega^2}\right)\right)} = 1$

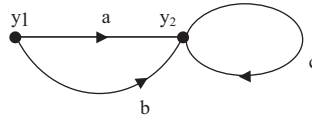
51. Number of state variable depends on the number of storage element i.e., Total number of L and C is 2.

52. Root locus start from poles and terminate at zero of GH. In present case pole are at $s = 0$ and $s = -4$ and zero at $s = -8$.

54. Proportional will give the output as the error signal and derivative will output as a step for a the ramp, so result is figure:



55.



$y_2 = (a + b) y_1 + c y_2$

i.e., $y_2(1 - c) = (a + b) y_1$

i.e., $\frac{y_2}{y_1} = \frac{a + b}{1 - c}$

56. $20 \log_{10} K = 40$

$\log_{10} K = 2$

$\therefore K = 100$

Corner frequencies = 10, 250

$\therefore = \frac{100}{(1 + j\omega T_1)(1 + j\omega T_2)}$

$G(s) = \frac{100}{\left(1 + \frac{s}{10}\right)\left(1 + \frac{s}{250}\right)}$

57. $G(s)H(s) = \frac{K K_p}{1 + s\tau}$

Positional error constant

$K_{pec} = \lim_{s \rightarrow 0} \frac{K K_p}{1 + s\tau}$
 $= K K_p$

Steady state error e_{ss}

$= \frac{1}{1 + K_{pec}} = \frac{1}{1 + K K_p}$

58. $T(s) = \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)} \frac{A}{1 + s\tau + A\beta}$

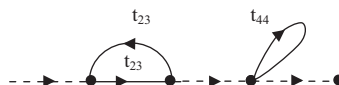
$= \frac{A}{s\tau + A\beta + 1} = \frac{A/(A\beta + 1)}{\frac{s\tau}{(A\beta + 1)} + 1}$

or $T(s) = \frac{\alpha}{\tau' s + 1}$

$\alpha = \frac{A}{A\beta + 1}$ and $\tau' = \frac{\tau}{(1 + A\beta)}$

Thus, time constant of $T(s)$, $\tau' = \frac{\tau}{(1 + A\beta)}$

61.



64. Initial value = $\lim_{s \rightarrow \infty} sN(s) \cdot I(s)$

$\lim_{s \rightarrow \infty} s \times \frac{1}{s} \times \frac{s+3}{4s+5}$
 $= \lim_{s \rightarrow \infty} \frac{s+3}{4s+5} = \frac{1}{4}$

Final value = $\lim_{s \rightarrow 0} sN(s) \cdot I(s)$

$= \lim_{s \rightarrow 0} s \times \frac{1}{s} \times \frac{s+3}{4s+5}$
 $= \lim_{s \rightarrow 0} \frac{s+3}{4s+5} = \frac{3}{5}$

66. Case: $\phi = \tan^{-1} \frac{\omega}{Z_1} - \tan^{-1} \frac{\omega}{P_1}$

For Lead compensator, $\phi > 0$, Then, $Z_1 < P_1$

Case: $\phi = \tan^{-1} \frac{\omega}{Z_2} - \tan^{-1} \frac{\omega}{P_2}$

For log compensator, $\phi < 0$,

Then, $Z_2 > P_2$

67. Characteristic equation

$1 + GH = 0$

or $s^4 + 5s^3 + 5s^2 + 4s + k = 0$

Apply RH criteria

s^4	1	5	k
s^3	5	4	0
s^2	$\frac{21}{5}$	k	0
s^1	$\left(\frac{84}{5} - 5k\right)$		
s^0	$\frac{21}{k}$	5	0

F

For stability, $\frac{84}{5} - 5k > 0$ and $k > 0$

Or $0 < k < 3.36$

68. For unit step input steady state error $\neq 0$ for type '0' system

$\frac{1}{1 + K} = 0.20$

$\Rightarrow K = 4$

$\therefore$ With unit integrator system becomes Type '1'. For Type '1' system with Ramp

input steady state error = $\frac{1}{K} = \frac{1}{4} = 0.25$

73. Apply RH table

s^4	2	3	10
s^3	1	5	
s^2	-7	10	
s^1	$\frac{45}{7}$		
s^0	10		

∴ R.H.S Root = 2

Since, only there are two sign changes, the number of roots in RHS s-plane is Two.

74. First method

$$(4s^2 + 36)Y(s) = 36X(s)$$

$$\frac{Y(s)}{X(s)} = \frac{36}{4s^2 + 36} = \frac{9}{s^2 + 9}$$

$$T(s) = \frac{9}{s^2 + 9}$$

$$\Rightarrow 2\delta\omega_n = 0$$

$$\Rightarrow \delta = 0 \text{ as } \omega_n = 3 \text{ rad/s}$$

$$t_s = \frac{4}{\int \omega_n}, t_s = \infty$$

$$\therefore \tau \text{ and } T_s \propto \frac{1}{\int} \Rightarrow \infty$$

75. Apply final value theorem

$$C_{ss} = \lim_{s \rightarrow 0} sC(s)$$

$$= \lim_{s \rightarrow 0} sR(s) \cdot H(s)$$

$$= \lim_{s \rightarrow 0} \frac{2(s+3)}{(s+2)(s+4)} = \frac{3}{4}$$

CHAPTER 10

LEVEL 1

22. In case FM

Modulation index

$$= \frac{\text{Maximum frequency deviation}}{\text{Highest modulating frequency}}$$

In case AM

$$\text{Modulation index} = \frac{E_m}{E_0}$$

25. Fidelity:

- It is the variation of the output with modulation frequency when the output load impedance is a resistance
- Reproduction of original modulating signal in respect to amplitude and frequency.

32. Equalizing pulse: One of the pulse occurring just before and just after the **vertical synchronizing** pulses in a television signal and serving to minimize the effect of lime-frequency pulses on interlace. The equalizing pulse occur at twice the line frequency and make each vertical deflection start at the correct instant for proper interlace.

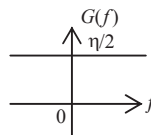
33. **Doppler radar:** A radar based on Doppler shift relative motion of source and observe

gives speed of moving vehicle. When the distance between source and observe is decreases, the observed frequency is higher than the source frequency. When the distance is increasing, the observed frequency is lower. The effect occurs for sound waves as well as radio waves.

43. The function of **padders** is ratio receivers is to improve tracking RF and Mixer and Local oscillator are ganged to avoid incorrect frequency fed to IF amplifier. Such error is called tracing error to avoid the tracking error a padder capacitor is connected in series with coil to neutralize the variation in frequency.

44. In PPM, information is contained in relative position of signal. Hence, a synchronizing signal is needed to establish the position reference. In PAM or PDM, on the other hand uncertainty about unmodulated amplitude or duration corresponds to a fixed DC offset that can be eliminated from the recovered signal by a simple RC network.

45. Power Spectral Density of white noise is constant and independent of frequency given by



48. Channel capacity,
 $C = BW \log_{10} (1 + S/N)$.

50. When the transmission path is very long or more repeater stations may be needed at intermediate points. These repeaters receive the signal while it is still larger than noise, remove the noise, amplify signal and retransmit if a long the channel.

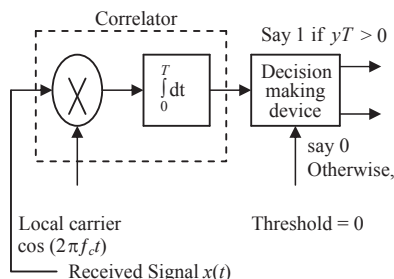
$$51. (S/N) = 2^{2n}$$

where, n = number of bit

Number of level, $M = 2^n$.

54. An envelope detector is a diode half wave rectifier followed by and RC-low pass detector. The output of the detector represents the envelope of the incoming high frequency signal. It is a **asynchronous** detection.

56.



$$59. \left(\frac{S}{N}\right)_{PCM} = 2^{2n} = M^2$$

where, $M = n$, number of steps.

60. Channel capacity is the maximum rate of information transmission

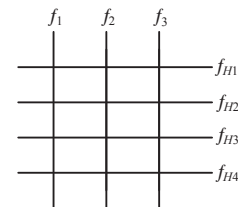
$$C = B \log \left(1 + \frac{S}{N} \right)$$

61. **Equalization** → Filtering operation i.e., to reshape for the detection purpose.

Retiming → Clock recovery i.e., this circuit provide a signal to sample the pulse at a optimum point.

Decision making → Reshaping i.e., to correct time and is of correct width.

62.



63. In a low level modulation AM system, the amplifiers following the modulated stage can be Class B untuned amp.

64. In the generation of modulated signal, a varactors diode can be used for FM generation only.

65. Pre-emphasis in FM systems involves (d) Amplification of higher frequency components of the modulating signal.

66. Condition to avoid clipping of detector output

$$RC \leq \frac{m_a \omega_m}{\sqrt{1 - m_a^2}}$$

67. As the modulation index of a FM signal with sinusoidal modulation is increased from zero to three, the power in the side-band component will Decrease continuously.

68. Double spotting in super heterodyne receivers is caused by Poor front-end rejection.

69. The amplifiers which are inserted at intervals to amplify the signal and compensate for transmission loss on the cable are called repeaters i.e., it reshaping regeneration, retiming for digital signal.

70. In an ADM transmission system, the output signal amplitudes for 1's and 0's are Variable but the repetition rate is fixed.

71. If, in a particular digital communication application, the receiver designed is an optimum coherent receiver, the channel noise is white and bits are transmitted using rectangular pulses, then which one

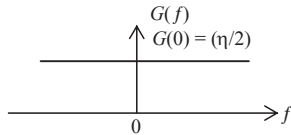
of the following statements would be INCONSISTENT (d) Sample, hold and dump receiver.

A correlator, Matched filter receiver, integrate and dump receiver are used for digital repetition under noisy condition.

72. The use of **non-uniform quantization** leads to increase in SNR for low level signals.
73. The baud rate is equal to twice the bandwidth of an ideal channel.
74. Preset equalization following the same process as adaptive equalization except that the equalization is set prior to transmission and then un-dated during breaks in transmission using (b) **block codes**.
75. Time division multiplexing requires: (a) Constant data transmission.

LEVEL 2

1. White noise is defined as any random process whose spectral density is constant and thus independent of frequency.



$$G(f) = G_0 = \text{constant}; -\infty < f < +\infty.$$

2. In phase modulation, the frequency deviation is: (a) Independent of the modulating signal frequency.
3. For distortion less transmission through a channel, the channel should be such that (b). Its attenuation response is flat and phase response is linear with frequency.
4. Quadrature multiplexing is the scheme where same carrier frequency is used for two different signals.
5. Threshold effect in demodulator is the rapid fall on output signal to noise ratio when the input signal to noise ratio falls below a particular value.
6. Leak type bias is used in a plate modulated class C amplifier Prevent excessive grid current.
8. In DPCM, we make a good a sample value from a knowledge of the past sample values. The sample values are not independent and generally there is a great deal of redundancy in the Nyquist samples. Proper exploitation of this redundancy leads to encoding a signal with a lesser number of bits.

10. $R_{\max} \propto \left[\frac{P_t D^4}{S_{\min}} \right]^{1/4}$

11. If $C \rightarrow$ the channel capacity representing the maximum possible information transmitted per second and

$B \rightarrow$ the channel bandwidth in Hz

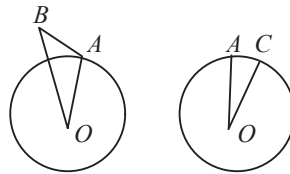
$$C = B \log \left(1 + \frac{S}{N} \right)$$

$$\Rightarrow C \propto B$$

13. 1. Spread spectrum is a means of transmission in which the data sequence occupies a band width in excess of the minimum band width necessary to send it.
2. The spectrum spreading is accomplished before transmission through the use of a code that is independent of data sequence.
3. It is performed by a code that is independent of the message signal. Wide-band angle modulation is not a spread spectrum scheme because its spectral spreading is done, not by an independent code, but by the message signal itself.
14. It is true only for SSB-SC but for SSI C power required is more for envelope detection. i.e., $A \gg |m(t)|$ vis-a-vis $A > |m(t)|$ as in case of AM.

16. WDM refer to wavelength Division multiplexing used as λ -multiplexing in OFC technology.

27.



Radius of the earth = 6370 km

$$AB^2 = OB^2 - OA^2$$

$$AB = \sqrt{(OB + OA)(OB - OA)}$$

$$= \sqrt{(6370.1 + 6370) \cdot 0.1}$$

$$= 80\sqrt{0.2}$$

Similarly,

$$AC = \sqrt{(6370.1 + 6370) \cdot 0.01} = 80\sqrt{0.2}$$

The range is $BC = BA + AC \approx 50$ km

28.
$$E = \frac{\sqrt{30P_t G_T}}{d} \ell_{\text{eff}}$$

$$= \frac{\sqrt{30 \times 20 \times 1.64}}{50 \times 10^3} \times 0.48 = 300 \mu V$$

29. $\cos^2 200 \pi t$ is multiplied by $\sin 200 \pi t$, the new signal

$$s(t) = \sin 200 \pi t \cos^2 200 \pi t$$

$$\text{or } s(t) = \sin 200 \pi t \left(\frac{\cos 400 \pi t + 1}{2} \right)$$

$$= \frac{1}{4} [\sin 200 \pi t + \sin 600 \pi t]$$

Thus the frequencies contained in the compounded signal are 100 Hz, 200 Hz, 300 Hz.

Product of tow signal

$$s(t) = \cos^2 200 \pi t \times \sin 200 \pi t$$

$$= \frac{1}{2} [1 + \cos 400 \pi t] \sin 200 \pi t$$

$$= \frac{1}{2} \sin 200 \pi t + \frac{1}{2} \cos 400 \pi t \cdot \sin 200 \pi t$$

$$= \frac{1}{2} \sin 200 \pi t + \frac{1}{4} \sin(-200 \pi t) + \frac{1}{4} \sin 600 \pi t$$

$$= \frac{1}{2} \sin 200 \pi t + \frac{1}{4} \sin 600 \pi t$$

$$\omega = 2\pi f \Rightarrow f = \frac{\omega}{2\pi}$$

The compounded signal contain 100 Hz, 300 Hz

31. Compression of PCM & DM System

1. The circuit required for PCM system is complex specially the design of quantizer is most difficult. In delta modulation system circuit required is very simple specially the demodulator
2. In PCM, $BW = (1/2) \eta f_s$ in DM. BW depend on f_s i.e. $f_s > \eta f_s$. Therefore BW required to transmit a signal using PCM system is less then that of DM.
DM: $BW = 100$ kHz
PCM: $BW = 64$ kHz (For same quality of reception)
3. The **error probability** in the case of PCM system is small so that the S/N ratio of PCM system is greater than that of DM system.

33. Total modulation index,

$$m_t = \sqrt{m_{a1}^2 + m_{a2}^2} = \sqrt{(0.4)^2 + (0.3)^2}$$

$$= \sqrt{0.16 + 0.09} = \sqrt{0.25} = 0.5$$

34. $P_T = P_C \left(1 + \frac{m_a^2}{2} \right)$

Or $P_T = P_C \left(1 + \frac{1^2}{2} \right)$

$$P_C = \frac{2}{3} P_T$$

35. PCM Bit rate = number of f_s

Where n = number of bits

36. Image frequency

$$f_{si} = f_s + 2f_i$$

$$= 1500 + 2 \times 455 = 1500 + 910 = 2410 \text{ kHz}$$

37. $P_{SSB}/P_c = P_c \frac{m_a^2}{4} = 800 \times \frac{0.81}{4}$

$$= 200 \times 0.81 = 162 \text{ watt}$$

38. $N = KTB = \left(\frac{V_N}{2R} \right)^2$

$$= \left(\frac{V_N^2}{4R} \right) N = \sqrt{4KT R_s B}$$

39. 1 dB power

$$= 10 \log_{10} P_c$$

$$\Rightarrow 10 \log_{10} P = \frac{1}{10}$$

40. F (local oscillator) $= f_s + f_{LF} = 1.15 + 0.47$
 $= 1.62 \text{ MHz}$

41. $1180 \text{ Hz} - 980 \text{ Hz} = 200 \text{ Hz}$.

42. $510 \text{ micro-second per half cycle} = 2 \times 510$
 $= 1020 \text{ } \mu\text{s/cycle} = 1.02 \text{ ms/cycle}$

$$\therefore \text{Signal frequency, } f = \left(\frac{1}{1.02} \times 10^3 \right)$$

$$= 980 \text{ Hz}$$

Hence, binary 1 is received on channel 1.

43. The upper side bands are given by $(f_c + f_m)$
 Lowest USB = $60 \text{ kHz} + 0.3 \text{ kHz} = 60.3 \text{ kHz}$

Highest USB = $60 \text{ kHz} + 3 \text{ kHz} = 63 \text{ kHz}$
 Therefore, range of upper side band = $60.3 \text{ to } 63 \text{ kHz}$

44. $P_T = P_c \left(1 + \frac{m_a^2}{2} \right)$

$$= P_c \left(1 + \frac{1}{2} \right) = 1.5 P_c$$

where P_T = total power

P_c = carrier power

m_a = modulation index.

45. FM (I.F) = 11.5 MHz

$$F(\text{image}) = f_s + 2f_{IF}$$

$$= 90.6 + 2 \times 11.5 = 112 \text{ MHz}$$

46. $M = 4$; $M = 2^n$ then $n = 2$

Information rate = $nf_s \uparrow = 10^6 \text{ bits/sec}$

$$f_s = \frac{10^6}{2} = 0.5 \times 10^6 = 0.5 \text{ MHz}$$

47. $\left(\frac{S}{N} \right)_{FM} = 3m_f^2 \left(\frac{S}{N} \right)_{AM}$

$$1 = 3m_f^2 \Rightarrow m_f = \frac{1}{\sqrt{3}}$$

48. Following frequencies will be present in the output.

$1000 \pm 0.3 = 1000.3 \text{ kHz}$ and 999.7 kHz
 and also $1000 \pm 2 = 1002 \text{ kHz}$ and 998 kHz

49. $m_a = m_{ef1} = \sqrt{m_1^2 + m_2^2}$
 $= \sqrt{(0.3)^2 + (0.4)^2} = 0.5$

$$P_T = P_c \left(1 + \frac{m_a^2}{2} \right)$$

$$P_T = 10 \text{ kW} \left(\frac{2 + 0.25}{2} \right)$$

$$= 10 \times 1.125 = 11.25 \text{ kW}.$$

50. $P_T = P_c \left(1 + \frac{m_a^2}{2} \right)$
 $= P_c \left(1 + \frac{0.8^2}{2} \right)$
 $= P_c (132)$

In DSB/SC saving in power is P_c ,
 therefore, power Saving

$$= \frac{P_c}{P_c \times 1.32} \times 100\%$$

$$= \frac{1}{1.32} \times 100 = 75.76\%$$

51. Picture elements (Pixel)

$$= 512 \times 512 = 262144$$

Information per picture element $n = \log_2 M$

$$\text{or } M = 2^n$$

$$\text{or } 8 = 2^n$$

$$\text{or } n = 3$$

Information for 262144 pixels
 $= 262144 \times 3$

$$= 784332 \text{ bits}.$$

Entropy is same as average information per message.

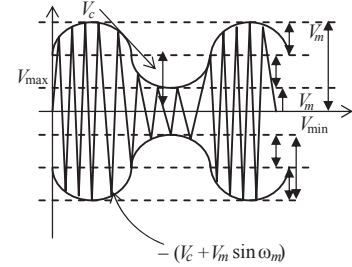
52. PCM Bandwidth $= \left(\frac{1}{2} \right) n f_s$

$$= \left(\frac{1}{2} \right) \times \text{Sampling rate} \times \text{Number of unit code}$$

$$= \frac{1}{2} \times 10 \times 7 = 35 \text{ kHz}$$

$$= 35 \text{ kHz}$$

- 53.



$$V_c = 12$$

$$V_m = 6$$

$$\text{Peak RF} = 2(12 + 6) = 2 \times 18 = 36 \text{ kv}$$

54. $m_a = \frac{V_{\max}}{V_c} = \left(\frac{4}{8} \right) = 0.5$

$$\frac{V_L^2}{R} = \frac{V_c^2}{R} \left(1 + \frac{m_a^2}{2} \right)$$

$$= 8^2 \left(1 + \frac{0.25}{2} \right)$$

$$= 8^2 \left(\frac{2.25}{2} \right) = 8^2 [1.125]$$

$$V_L = 8.64 \text{ (r.m.s voltage)}$$

$$V_L (\text{peak to peak}) = 8.64 \times \sqrt{2}$$

$$= 8.64 \times \sqrt{2} = 12.21$$

$$= 12.21 \approx 12 \text{ (Approx)}$$

55. $f_s > 2f_m$; $f_s = 2 \times 2 = 4 \text{ kHz}$

$$\text{PCM bandwidth} = \left(\frac{1}{2} \right) n \cdot f_s$$

$$= \left(\frac{1}{2} \right) \times 4 \times 4 = 8 \text{ kHz}$$

56. Channel capacity $C = B \log_2 (1 + S/N)$

$$= 4 \log_2 (1 + 15)$$

$$= 4 \log_2^{16}$$

$$= 4 \log_2 (2)^4$$

$$= 4 \times 4 = 16$$

57. $H = \sum_{n=1}^n \left(\frac{1}{P_n} \right) \log_2 \left(\frac{1}{P_n} \right)$

$$= \log_2 40$$

$$= 5.32$$

$$M \geq 2^n$$

$$40 \leq 2^6$$

$$n = 6$$

58. In present case: $F_1 = F_2$

$$10 \text{ dB} = 10 \log_{10} G_1$$

$$1 = \log_{10} G_1$$

$$G_1 = 10^1 = 10$$

$$F = F_1 + \frac{F_2 - 1}{G_1} = 10 + \frac{9}{10} = 10.9$$

$$59. 16 = 2^n \Rightarrow n = 4$$

$$f_m = 4 \text{ kHz}$$

$$f_s = 2f_m = 2 \times 4 = 8 \text{ kHz}$$

$$\begin{aligned} \text{Transmission bit rate} &= n \times f_s \\ &= 4 \times 8 \text{ kHz} \\ &= 32 \text{ kHz} \end{aligned}$$

$$60. \Delta f = BW = (20 - 18 \text{ MHz})$$

$$= 2 \text{ MHz} = 2 \cdot 10^6$$

$$T^\circ \text{K} = 273 + 27 = 300^\circ \text{K}$$

$$R = 10 \text{ k}\Omega = 10 \times 10^3$$

RMS Noise voltage

$$V_{rms} = \sqrt{4KTR \Delta f}$$

$$V_{(N)rms}$$

$$= \sqrt{2 \cdot 10^6 \cdot 10 \cdot 10^3 \cdot 300 \cdot 1.38 \cdot 10^{-23}}$$

61. If carrier modulated by a digital bit stream had one of the possible phases of 0, 90, 180 and 270 degrees, then the modulation is called QPSK

62. A mixer, since it yields sum & difference frequency, will translate the spectrum of an FM signal, but will have no effect on its frequency deviation.

63. Number of Bit

$$\begin{aligned} &= (\text{Number of Bit} + \text{synchronization Bit}) \\ &\times (\text{sampling Frequency}) \times (\text{number of Channel}) \end{aligned}$$

$$\begin{aligned} &= (7 + 1) \times 8000 \times 20 \\ &= 64000 \times 20 = 1280000 \\ &= 1280 \text{ k bits/sec} \end{aligned}$$

64. Total attenuation

$$\begin{aligned} &= (1 \text{ dB/km} \times 1000 \text{ km}) \\ &= 1000 \text{ dB} \end{aligned}$$

$$= 20 \log_{10} \left(\frac{V_1}{V_2} \right)$$

$$1000 = 20 \log_{10} \left(\frac{V_1}{V_2} \right)$$

$$\text{Here } V_1 = 1 \text{ V}$$

$$\Rightarrow \frac{V_1}{V_2} = 10^{50} \Rightarrow V_2 = \frac{V_1}{10^{50}}$$

$$V_2 = 10^{-50} \text{ V}$$

$$65. 2^n = 64 \Rightarrow n = 6$$

$$f_s = (2 \times 5) = 10 \text{ kHz}$$

$$\begin{aligned} \text{Transmission rate } r &= nf_s = 6 \times 10 \\ &= 60 \text{ kHz} \end{aligned}$$

$$66. C = B \log_2 \{1 + S/N\}$$

$$\begin{aligned} \Rightarrow &= 4 \log_2 (1 + 31) \\ &= 4 \log_2 32 = 4 \times 5 \\ &= 20 \text{ Mbs} \end{aligned}$$

68. Entropy of source H(x)

$$-0.5 \log_2 \frac{1}{0.5} + 0.25 \log_2 \frac{1}{0.25} + \dots$$

$$= 0.125 \log_2 \frac{1}{0.25} +$$

$$\frac{0.125 + \log_2 \frac{1}{0.125}}{\Downarrow}$$

$$-0.5 \log_2 (2) + 0.25 \log_2 (4) + \dots$$

$$= 0.125 \log_2 (8) + 0.125$$

$$\Downarrow + \log_2 (8)$$

$$-0.5 \log_2 (2^1) + 0.25 \log_2 (2^2) + \dots$$

$$= 0.125 \log_2 (2^3) +$$

$$\Downarrow 0.125 + \log_2 (2^3)$$

$$= [0.5 \times 1 + 0.25 \times 2 + 0.125 \times 3 + 0.125 \times 3]$$

$$= [0.5 + 0.5 + 0.25 \times 3] = 1.75 \text{ bit/sec.}$$

$$69. = 15 \text{ dB} = 10 \log_{10} (S/N)$$

$$(S/N) = (10)^{1.5} = 31$$

$$\text{Channel capacity, } C = B \log_2 (1 + S/N)$$

$$= 4 \log_2 (1 + 31) = 4 \log_2 (32)$$

$$= 4 \text{ kHz} \times 5$$

$$= 20 \text{ kHz} = 20,000 \text{ bps}$$

70. If transmission is accomplished by encoding the signals into binary digits and signal are equally likely to occur then the average information (Entropy) is given by

$$H(x) = \log_2 M = \log_2 2^n = n \log_2 2 = n$$

$$\text{In present case } M = 2^n; 16 = 2^n; n = 4$$

$$H(x) = n = 4$$

$$71. T_e = (F - 1) \cdot T_o$$

Where, T_e = Temperature equivalent of noise

$$T_o = \text{Room temperature in Kelvin}$$

$$F = \text{Noise figure}$$

$$T_e = (1.6 - 2) \cdot 290 = 174.99 \text{ K}$$

$$74. BW_{FM} = 2(\delta + f_m)$$

The deviation does not depend on carrier frequency.

$$75. P_T = P_C \left(1 + \frac{m_a^2}{2} \right)$$

$$\Rightarrow \frac{600}{400} = 1 + \frac{m_a^2}{2} \Rightarrow \frac{3}{2} = 1 + m_a^2$$

$$\Rightarrow \frac{1}{2} = \frac{m_a^2}{2}$$

$$m_a = 1$$

LEVEL 3

1. Power spectrum $G(\omega) = |F(\omega)|^2$

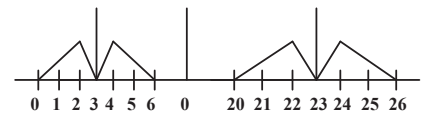
$$\text{Since } \sin^2 a t = \frac{1}{2}(1 + \cos 2 a t)$$

In power spectrum term the frequency becomes double. In power spectrum figure the frequency is 2 kHz but originally this will have the frequency of 1 kHz. Hence, minimum sampling rate of this deterministic signal is $2 \times 1 \text{ kHz} = 2 \text{ kHz}$

2. The output after BM = $10 \pm f_x$

$$\text{Output after HPF} = 10 + f_x$$

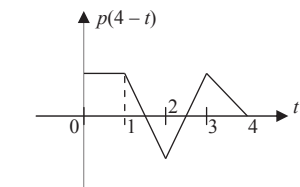
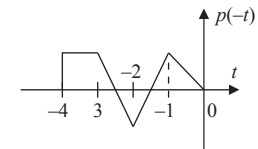
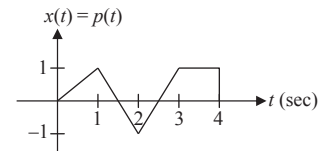
$$\begin{aligned} \text{Output after next BM} &= 13 \pm (10 \pm f_x) \\ &= 23 + f_x \text{ and } 3 - f_x \end{aligned}$$



3. Given $p(t) = x(t)$

Matched filter output is given by equation

$$h(t) = [2k/\eta] p(T - t)$$



Slope between 3 and 4 sec
= -1 sec

4. Power in $m(t) = P_m$

$$y(t) = [m(t)/2] [2 \cos \omega_o t \cos (\omega_o t + \theta)]$$

$$= [m(t)/2] [\cos (2\omega_o t + \theta) + \cos \theta]$$

after paring *L.P.F*

$$y(t) = [m(t)/2] \cos \theta$$

$$\text{Power} = \frac{1}{T} \int_0^T \left| \frac{m(t)}{2} \cos \theta \right|^2 dt$$

$$= \frac{1}{T} \int_0^T \frac{m^2(t)}{4} \cos^2 \theta dt = \frac{\cos^2 \theta}{4} \cdot P_m$$

$$\Delta \phi = 2\pi \sqrt{30^2 + 40^2}$$

$$= 100\pi$$

$$\begin{aligned} 5. \quad y_1(t) &= m(t) \cdot s(t) = \frac{2 \sin 2\pi t \cdot \cos 200t}{t} \\ &= \frac{\sin(202\pi t) - \sin(198\pi t)}{t} \end{aligned}$$

$$y_2(t) = y_1 + n(t)$$

$$= \frac{[\sin(202\pi t) - \sin(198\pi t) + \sin 199\pi t]}{t}$$

$$y_2(t) = y_1 + n(t)$$

$$\begin{aligned} &[\sin(202\pi t) - \cos(200\pi t) \\ &- \sin(199\pi t) \cdot \cos 200\pi t] \\ &= \frac{t}{t} \end{aligned}$$

$$+ \frac{\sin(199\pi t) \cdot \cos(200\pi t)}{t}$$

$$\{1/2t\} [\sin(402\pi t) + \sin 2\pi t]$$

$$- \{1/2t\} [\sin 398\pi t - \sin 2\pi t]$$

$$+ \{1/2t\} [\sin 399\pi t - \sin \pi t]$$

$$= \{1/2t\} [\sin 402\pi t + \sin 399\pi t - \sin 398\pi t + 2 \sin 2\pi t - \sin \pi t]$$

Cut off frequency = 1 KHz

$$\omega_1 = 2\pi$$

$$\omega_2 =$$

$$\text{After LPF} = \{1/2t\} [\sin 2\pi t + \sin 2\pi t - \sin \pi t]$$

$$= \{1/2t\} [\sin 2\pi + \cos\{3\pi t/2\} \cdot \sin\{\pi t/2\}]$$

$$= \{1/2t\} [\sin 2\pi + \cos 1.5\pi t \cdot \sin 0.5\pi t]$$

$$= \left(\frac{1}{2}\right) \frac{\sin 2\pi t}{t} + \frac{\sin 0.5\pi t}{t} \cdot \cos 1.5\pi t$$

$$[\sin A - \sin B] = 2 \cos [(A+B)/2] \cdot \sin [(A-B)/2]$$

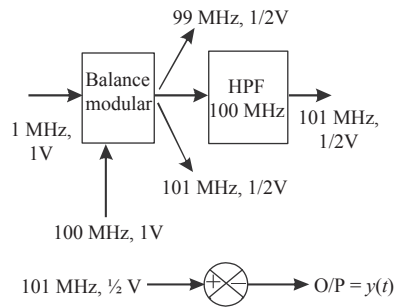
$$\begin{aligned} 6. \quad i_c(t) &= i_{c(\text{initial})} e^{-\frac{t}{RC}} + i_{c(\text{initial})} \left(1 - e^{-\frac{t}{RC}}\right) \\ &= \frac{1}{2} \cos 2\pi(10^8 t) \cos 2\pi(10^6 t) \end{aligned}$$

$$\begin{aligned} &- \frac{1}{2} \sin 2\pi(100 \cdot 10^6 t) \sin 2\pi 10^6 t \\ &+ \sin \pi(100 \cdot 10^6 t) \frac{1}{2} \sin 2\pi(10^8 t) \\ &\cos 2\pi(10^6 t) - 1 - \frac{7}{2} \sin 2\pi(10^8 t) \end{aligned}$$

So envelope detector output

$$\begin{aligned} &\left[\frac{1}{4} \cos^2(\omega_m t) + \left(1 - \frac{1}{2} \sin \omega_m t\right)^2 \right]^{1/2} \\ &= \sqrt{\frac{5}{4} - \sin(2\pi \times 10^6)} \end{aligned}$$

Another Method



$$\begin{aligned} y(t) &= \frac{1}{2} \cos\{2\pi \cdot 101 \cdot 10^6\} t \\ &+ \sin 2\pi \cdot 100 \cdot 10^6 t \end{aligned}$$

$$\begin{aligned} &= \frac{1}{2} \cos\{2\pi 100 \times 10^6\} t + \cos 10^6 t \cdot 2\pi \\ &- \sin(2\pi \times 100 \times 10^6) t \sin 2\pi 10^6 t \\ &+ \sin 2\pi \times 100 \times 10^6 t \end{aligned}$$

$$\begin{aligned} &= \frac{1}{2} \cos 2\pi 100 \times 10^6 t [\cos 2\pi \times 10^6] \\ &+ \frac{1}{2} \sin 2\pi \times 100 \times 10^6 t [\sin 2\pi \times 10^6 t + 2] \end{aligned}$$

$$= A \cos 2\pi \times 10^6 t + B \sin \cos 2\pi \times 10^6 t$$

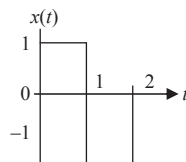
$$\text{Envelop} = 17 \angle 30$$

$$= \sqrt{\frac{1}{4} \cos^2 2\pi \times 10^6 t + \frac{1}{4} [\sin 2\pi \times 10^6 t - 2]}$$

$$\text{Envelop} = \sqrt{\frac{5}{4} - \sin 2\pi \times 10^6 t}$$

7. To equalize output of low pass filter a High pass filter i.e., differentiator circuit is required.

$$9. \quad x(t) = u(t) - 2u(t-1) + u(t-2) \text{ for } x(t)$$



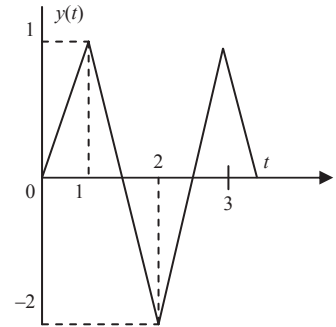
The impulse of a matched filter is delayed version of the input.

Now delay not given, so assumed to be zero.

$\therefore y(t) = x(t) * x(t)$ [where $*$ represent convolution.]

$$y(t) = r(t) - 4r(t-1) + 6r(t-2) - 4r(t-3) + r(t-4)$$

Hence $u(t) * u(t) = r(t)$ Ramp function.

**10. Form plot, $p(v) = [k/4]_v$**

Total probability

$$= \int_0^4 pv \, dv = 1, \quad \int_0^4 [k/4]v \, dv$$

$$\left. \frac{k}{4} \frac{v^2}{2} \right|_0^4 = 1 \text{ or } 2k = 1$$

$$\Rightarrow k = [1/2]$$

mean square value of

$$v = \int_0^4 vp(v) \, dv = \int_0^4 v \cdot [k/4]v \, dv$$

Mean square value = 8

11. The value of C should be equal to quantization error = $[\Delta^2/12]$

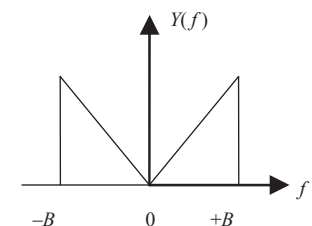
12. This diagram represent SSB generation by phase shift method

$$\text{For USB, } r(t) = m(t) \cos \pi Bt - m'(t) \sin 2\pi Bt$$

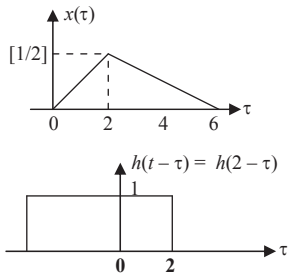
$$\text{For LSB, } r(t) = m(t) \cos \pi Bt + m'(t) \sin 2\pi Bt$$

Since $y(t)$ is sum of both

$\therefore$ It is LSB generator and its Fourier transform $Y(f)$ is given as:



13.



The above figure demonstrate the process of convolution. The output $y(t)$ of the system is given by

$$\begin{aligned} y(t) &= \int x(\tau) h(t-\tau) d\tau \\ y(2) &= \int x(\tau) h(2-\tau) d\tau \\ &= \int_0^2 [(1/4) \cdot \tau] \cdot 1 \cdot d\tau \\ &= \frac{1}{4} \times \left[\frac{\tau^2}{2} \right]_0^2 = \frac{1}{4} [2-0] = [1/2] \end{aligned}$$

14. Mean $\bar{x} = \int_{-1}^3 xp(x)dx = \int_{-1}^3 x[1/4]dx$

$$\frac{1}{4} \left(\frac{x^2}{2} \right)_{-1}^3 = \frac{1}{4 \times 2} [9-1] = \frac{8}{8} = 1$$

variance $\sigma^2 = \int_{-1}^3 x^2 p(x) - (\bar{x})^2$

= Second moment - (mean)²

$$= \frac{1}{4} \int_{-1}^3 x^2 dx - (\bar{x})^2$$

$$= \frac{1}{4} \left(\frac{x^3}{3} \right)_{-1}^3 - (\bar{x})^2$$

$$= [1/12] [27+1] - 1$$

$$= [1/12] \times 28 - 1 = [(7-3)/3] = [4/3]$$

15. Magnitude (W_1) $\mu [1/n] = x n^{-1}$

(W_2) $\mu [1/n^2] = z n^{-2}$

17. $\omega_0 = \frac{2\pi}{[T_0/6]} = 2\pi \times 6000 \text{ rad/s}$

18. Equation of the line joining (-2) and (0.25) is

$$\frac{Y-0}{X+2} = \frac{0.25-0}{1+2}$$

$$\therefore [0.25/3] (x+2) = [1/12] (x+2)$$

Thus in $-2 \leq x \leq 1$, $f(x) = [1/12] (x+2)$

$$\therefore f(x) = f'(x) = [1/12]$$

Now, $P(X=1) = \int_{-2}^1 f(x) dx$

$$\int_{-2}^1 [1/12] dx = \frac{1}{12} (x) \Big|_{-2}^1 = \frac{1}{4}$$

19. $S(t) = 1 [1 + 2 \cos \omega_s t + 2 \cos 2\omega_s t + \dots]$

$$\cos^2 4\pi \times 10^3 t = \frac{1 + \cos 8\pi \times 10^3 t}{2}$$

$$\omega_s = \frac{2\pi}{0.1 \times 10^{-3}} = 2\pi \times 10 \times 10^3$$

$$s(t) * x(t) \int_{-\infty}^{\infty} s(\tau) x = (\tau - t) d\tau$$

$$= \int 10 \times 10^3 [1 + 2 \cos \omega_s t + 2 \cos 2\omega_s t + \dots] \times$$

$$\left[\frac{1 + \cos 8\pi \times 10^3 t}{2} \right] dt$$

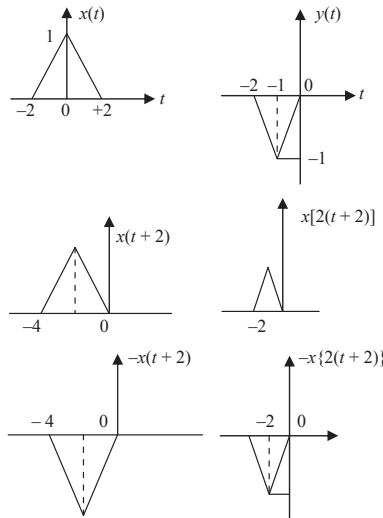
So, frequencies present will be $f_s \pm f_m$, $2f_s \pm 3f_s \pm f_m$

$$f_s = 10 \text{ KHz}$$

$$f_m = 8\pi \times 10^3 = 4 \text{ KHz}$$

Hence 14 KHz sinusoidal signal will be present

20.



$$x(t-t_0) \rightarrow X(f) e^{-j2\pi f t_0}$$

$$x(at) \rightarrow [1/|a|] X(f/a)$$

$$y(t) = -x[2(t+2)] \rightarrow -[1/2] X(f/2) e^{-j2\pi f t_0}$$

21. PCM BW = $\left(\frac{1}{2} \right) n \cdot f_s$

$$= \left(\frac{1}{2} \right) \cdot n \cdot f_m$$

$$= n f_m = n_f$$

22. $m_a = \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}} = \frac{10-5}{10+5} = \frac{1}{3} = 0.33$

24. $F = 1 + \frac{R_{sp}}{R_a} = 1 + 1 = 2$

25. $m_{a1} = 30\% = 0.3$

$$m_{a2} = 40\% = 0.4$$

$$m_{ef1} = \sqrt{m_1^2 + m_2^2}$$

$$= \sqrt{(0.3)^2 + (0.4)^2} = 0.5$$

$$P_T = P_C \left(1 + \frac{m_a^2}{2} \right)$$

$$V_{rms} = \sqrt{\frac{1}{T} \int_0^T x^2(t) dt}$$

$$= 10 \times 1.125$$

$$= 11.25 \text{ kW}$$

26. $13 = 10 \log_{10} \left(\frac{P}{1 \text{ mW}} \right)$

$$\left(\frac{P}{1 \text{ mW}} \right) = (10)^{1.3}$$

$$P = 20 \text{ mW}$$

27. $FDM_{BW} = n f_m + (n-1) f_g$

where, f_m = Signal frequency

f_g = Guard Band frequency

In present case, $n = 12$

$$\begin{aligned} FDM_{BW} &= n f_m + (n-1) f_g \\ &= 12 \times 5 + (11 \times 1) \\ &= 60 + 11 = 71 \text{ kHz} \end{aligned}$$

28. $F_{\text{image}} = f_s + 2f_{IF} = 1200 + 910 = 2110 \text{ kHz}$

29. Transmission rate = $n f_s$

where, n = number of bits

f_s = sampling frequency

$$= 2f_s$$

$$m = 2^n$$

$$4 = 2^n; n = 2$$

Transmission rate = $n f_s$

$$= 2 \times 6 \text{ MHz}$$

$$= 12 \text{ MHz}$$

30. Noise B.W = Constant

$$\left[\frac{\text{Noise}}{2} \right] 2 BW = \text{Constant}$$

$$[S/N]_{dB} - 30 = 10 \log_{10} [S/N]$$

$$[S/N] = 100$$

In second case

$$[N/2] = N$$

$$2 [S/N] = 2000 = 10 \log_{10} 2000$$

$$= 33 \text{ dB}$$

31. Slope of signal, $m_1 = \left(\frac{dm(t)}{dt} \right) = a$

Slope of signal, $m_2 = \left(\frac{\delta}{T_s} \right)$

To avoid slope over load distortion

$$|m_1| \leq |m_2|$$

$$a \leq \left(\frac{\delta}{T_s} \right)$$

$$\delta \geq aT_s$$

32. $\left(\frac{S}{N} \right)_{db} = 1.76 + 6.02 \cdot n$
 $= 1.76 + 6.02 \times 8 \cong 48 \text{ dB}$

33. Hamming codes.

Consider a family (n, k) linear block codes that have the following parameters:

Block length $n = 2^m - 1$

Number of message bits: $k = 2^m - m - 1$

Number of parity bits: $n - k = m$

where $m \geq 3$. These are the so-called Hamming codes.

Consider the Hamming code with $n = 7, k = 4$, corresponding to $m = 3$. The generator matrix of the code must have a structure that conforms. The following matrix represent an appropriate generator matrix for the Hamming code:

$$G = \begin{bmatrix} 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 & 1 \end{bmatrix} \downarrow$$

$$\equiv \underbrace{\begin{bmatrix} 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 0 \end{bmatrix}}_P \underbrace{\begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}}_{I_k} \downarrow$$

No. Parity bits ($n - k = m$)	No. of message bits: ($k = 2^m - m - 1$)	Block length ($n = 2^m - 1$)
$m = 1$	$2^1 - 1 - 1 = 0$	$2^1 - 1 = 1$
$m = 2$	$2^2 - 2 - 1 = 4 - 3 = 1$	$2^2 - 1 = 4 - 1 = 3$
$m = 3$	$2^3 - 3 - 1 = 8 - 4 = 4$	$2^3 - 1 = 8 - 1 = 7$
$m = 4$	$2^4 - 4 - 1 = 16 - 5 = 11$	$2^4 - 1 = 16 - 1 = 15$
$m = 5$	$2^5 - 5 - 1 = 32 - 6 = 26$	$2^5 - 1 = 32 - 1 = 31$
$m = 6$	$2^6 - 6 - 1 = 64 - 7 = 57$	$2^6 - 1 = 64 - 1 = 63$
$m = 7$	$2^7 - 7 - 1 = 128 - 8 = 120$	$2^7 - 1 = 128 - 1 = 127$

34. $f_m = 100 \text{ Hz}$
 $m_f = 15$

$$m_f = [\delta / f_m] \Rightarrow \delta = m_f \cdot f_m = (1500) \text{ Hz}$$

$$B.W = 2(\delta + \delta_m)$$

$$= 2(1500 + 100)$$

$$= 3.2 \text{ kHz}$$

35. f_s (Nyquist) $= 2f_m$
 f_s (Present) $= 2f_s$ (Nyquist)
 Transmission $BW = n \cdot f_s$ (Present)
 $= 4 \times 2(2 \times 5 \text{ kHz})$
 $= 80 \text{ kHz}$

37. $P_t = 10 \text{ kW}$, $m_a = 0.6$
 Transmitted power $P_t = P_c + P_s$
 or $P_t = P_c \{1 + m_a^2\}/2\}$
 $P_t = P_c \left(\frac{1 + m_a^2}{2} \right)$
 or $P_c = \frac{10}{\left(\frac{1 + m_a^2}{2} \right)} = \frac{10}{\left(1 + \frac{0.6^2}{2} \right)}$
 $= 8.47 \text{ kW}$

38. From the given signal expression,
 $\theta(t) = 2 \times 10^8 \pi t + 75 \sin 2 \times 10^3 \pi t$
 and $\phi(t) = 75 \sin 2 \times 10^3 \pi t$
 $\frac{d\phi}{dt} = 75 \times 2 \times 10^3 \pi \cdot \cos$

Then, peak frequency deviation

$$|\phi'(t)|_{\max} = \frac{7.5 \cdot 2 \cdot 10^3 \pi}{2} = 75 \text{ kHz}$$

39. $\left(\frac{S}{N} \right)_{dB} = 1.76 + 6.02n$
 $\left(\frac{S}{N} \right)_{dB} = 1.76 + 6.02 \times 2$

Increase in $\left(\frac{S}{N} \right)$ is 6 db for each bit

40. For a given data rate the bandwidth β_p of a BPSK signal and the bandwidth β_o of the OOK signal are related as (d) $\beta_p = \beta_o$
41. A source generates **four equiprobable symbols**. If the source coding is adopted, the average length of code for 100 per cent efficiency is 2 bits per symbol

Proximity of symbols	First	Second
(1/4)	0	00
(1/4)	0	01
(1/4)	1	10
(1/4)	1	11

42. If all input signals have the same bandwidths f_m and are sampled equally, then

the minimum bandwidth for TDM is $f_{TDM} \geq n f_m$

where n is the number of the multiplexed signals

43. The efficiency η of ordinary AM for a single-tone modulation $= \frac{m_a^2}{2 + m_a^2} \times 100\%$

where m_a is the percent modulation.

For $m_a = 1, \eta = 33.3\%$ for ordinary AM

For DSB-SC, $\eta = 100\%$ as $P_c = 0$ (carrier power)

$$P_t = P_c \left[1 + \frac{m_a^2}{2} \right]$$

For DSB/SC

$$P_t = P_c \left[\frac{m_a^2}{2} \right]$$

DSB/SC

Power saving %

$$= \frac{P_c}{P_c \left[1 + \frac{m_a^2}{2} \right]} \times 100$$

$$= \frac{2}{3} \times 100$$

$$= 66\%$$

$\Rightarrow$ Power saving is = 66%

44. Noise figure $F = \frac{(S/N)_i}{(S/N)_o}$

$$38 \text{ dB} = 10 \log \left(\frac{S}{N} \right)_o$$

$$\log \left(\frac{S}{N} \right)_o = \frac{38}{10} = 3.8$$

$$\left(\frac{S}{N} \right)_o = (10)^{3.8} = 6309.573$$

$$6 \text{ dB} = 10 \log F$$

$$\log F = 0.6$$

$$\left(\frac{S}{N} \right)_o = \frac{(S/N)_i}{F}$$

$$= \frac{6309.573}{3.98}$$

$$= 1585.32$$

$$= 10 \log 1585.32$$

$$= 32 \text{ dB}$$

Second method

$$F = \frac{(S/N)_i}{(S/N)_o}$$

$$10 \log F = \frac{10 \log \left(\frac{S}{N} \right)_i}{10 \log \left(\frac{S}{N} \right)_o}$$

$$6 \text{ dB} = \frac{38 \text{ dB}}{10 \log \left(\frac{S}{N} \right)_o}$$

$$10 \log \left(\frac{S}{N} \right)_o = \frac{38 \text{ dB}}{6 \text{ dB}}$$

$$= 38 \text{ dB} - 6 \text{ dB} = 32 \text{ dB}$$

46. $2f_{IF} = 2500 - 1600 = 900 \text{ kHz}$
 $\Rightarrow f_{IF} = 450 \text{ kHz}$

47. maximum slope = $\frac{\text{step height}}{\text{step width}}$
 $= 75/1.5 = 50 \text{ V/s}$

48. Power spectral density is an even function of ω i.e., frequency only.

49. $\frac{P_s}{P_t} = \frac{m_a^2}{2 + m_a^2}$
 $P_s \rightarrow$ sideband power

$$P_c \rightarrow \text{Carrier power}$$

$$P_t \rightarrow \text{Total power}$$

$$\therefore \frac{P_t - P_c}{P_t} = \frac{1}{2 + 1}$$

$$m_a^2 = 1$$

$$\therefore 3P_t - 3P_c = P_t$$

$$\Rightarrow P_t = \frac{3}{2}P_c = 1.5 P_c$$

51. Image frequency = carrier frequency
 $+2 \times IF$
 $= 1000 + \times 455$
 $= 1910 \text{ kHz}$

52. Min Nyquist rate = $2(\omega + \omega_c)$
 $= 2(1 \text{ MHz} + 4 \text{ GHz})$
 $\cong 2 \times 4 \text{ GHz}$
 $= 8 \text{ GHz}$

53. $\frac{P_{t1}}{P_{t2}} = \frac{\frac{1}{2}A^2 \left(1 + \frac{m_{a1}^2}{2} \right)}{\frac{1}{2} \left(1 + \frac{m_{a2}^2}{2} \right) A^2}$

$$m_{a1} = 0$$

$$m_{a2} = 1$$

$$P_{t2} = \frac{3}{2}P_{t1} = 1.5 P_{t1}$$

$$\frac{P_{t2} - P_{t1}}{P_{t1}} = 0.5 \times 100 = 50\%$$

54. $FT \equiv x(-t) \overset{\infty}{\underset{-\infty}{\int}} x(-t) e^{-j\omega t} dt$
 $= \int_{-\infty}^{\infty} x(\lambda) e^{-j\omega \lambda} d\lambda$

$$= \int_{-\infty}^{\infty} x(\lambda) e^{-j(-\omega)\lambda} d\lambda = X(-\omega)$$

if $x(t)$ is real, then

$$\int_{-\infty}^{\infty} x(\lambda) e^{j\omega \lambda} d\lambda = \int_{-\infty}^{\infty} x(\lambda) e^{-j\omega \lambda} d\lambda^*$$

$$\equiv \int_{-\infty}^{\infty} x^*(\omega) d\omega$$

$$\text{or } X(-\omega) = X^*(\omega)$$

$$\text{or } X(-f) = X^*(f)$$

55. Using Time shift Laplace operation similar for Fourier transform.

$$x(t) \rightarrow F(s)$$

$$x(t - 2) \rightarrow F(s)e^{-2s}$$

Then

$$Y(\omega) = 2e^{-j4\pi f} X(\omega)$$

$$y(t) = 2x(t - 2)$$

56. Refer M-ARY communication

$$I_m = \log_3 M = 3$$

$$\Rightarrow M = 27$$

57. Let, $m(t) \rightarrow$ modulating signal.

If $m(t) = a_m \cos \omega_z t$, then the waveform is PM and

If $m(t) = a_m \sin \omega_z t$, then the waveform is FM

Second method

By looking at an angle modulated carrier, there is no way of telling whether it is FM or PM without the knowledge of modulating signal.

58. $x(t) = 5 \cos(50t + \sin 5t)$

$$= 5 \cos \theta$$

$$\omega_i = \frac{d\theta}{dt} = \frac{d}{dt}(50t + \sin 5t)$$

$$= 50 + 5 \cos(5t)$$

$$\text{At } t = 0,$$

$$\omega_i = 50 + 5 \cos 0^\circ = 50 + 5$$

$$\omega_i = 55 \text{ rad/sec}$$

59. Modulation index $\beta = \frac{\Delta f}{f_m}$

$$\Rightarrow \Delta f = 50 \times 500 = 25000 \text{ Hz}$$

60. $v_n = \frac{n\lambda f_p}{2}$

$$\Rightarrow v_1 = \frac{1 \times 5 \times 10^{-2} \times 1000}{2} = 25 \text{ m/s.}$$

61. $f_c + f_m = 705 \text{ kHz}$,

$$2f_m = 10 \text{ kHz} \Rightarrow f_c = 700 \text{ kHz.}$$

62. $P_t = P_c \left(1 + \frac{m_a^2}{2} \right)$

$$P_{SB} = P_c \left[\frac{m_a^2}{4} \right]$$

$$\text{Let } m_a = 1$$

$$\% P_{SB} = \frac{(P_c/4) \times 100}{(3P_c/2)}$$

$$= \frac{1}{6} \times 100 = 16.67\%$$

66. $x_{AM}(t) = [A + m_a A \cos \omega_m t] \cos \omega_c t$

$$\text{Here } A + m_a A = 2A$$

$$\text{Or, } m_a = 1 \quad \text{or } 100\%$$

Second Method

$$A + m_p = 2A$$

$$\Rightarrow m_p = A$$

$$\Rightarrow m_a = \frac{m_p}{A} = 1$$

i.e., 100%

67. $F = \frac{S_i/N_i}{S_o/N_o} = \frac{S_i \times N_o}{N_i \times S_o}$

69. Using $(-jt).x(t) \leftrightarrow F \frac{d}{d\omega} X(\omega)$

$$\text{And } \frac{1}{j\omega + a} \leftrightarrow F e^{-at} u(t)$$

$$\text{We have, } X(j\omega) = \frac{1}{|a + j\omega|^2}$$

70. $V_{AM}(t) =$

$$= A_c \cos \omega_c t + A_c m(t) \cos \omega_c t$$

$$= A_c \cos \omega_c t + A_c \cdot 0.8$$

$$\sin(2\pi \cdot 10^3 t) \cos \omega_c t$$

$$= 500 \cos \omega_c t + 400 \sin(2\pi \times 10^3) \cos \omega_c t$$

Average power dissipated in the load (50 Ω)

$$= \frac{V^2}{R} = \frac{(500)^2}{2 \times 50} + \frac{(400)^2}{4 \times 50} = 3.3 \text{ kW}$$

71. $P_t = P_c \left(1 + \frac{m_a^2}{2} \right)$

$$\text{or } 125 = P_c \left[1 + \frac{(0.70)^2}{2} \right]$$

$$\text{or } P_c = 100 \text{ kW}$$

72. given, $f_s = 555 \text{ Hz}$
 $f_{Lo} = 1010 \text{ kHz}$
 $f_{IF} = f_s + f_{IF}$
 $\therefore f_i = f_o - f_s = 1010 - 555 = 455 \text{ kHz}$
 Image frequency
 $f_{si} = 555 + 2 \times 455 = 1465 \text{ kHz}$
73. $P_c = \frac{A_2}{2 \times 50} = 40 \times 1000$
 $\Rightarrow A = 2 \text{ kV}$
 $m_p = m_a A = (0.707) \times 2 = 1.414 \text{ kV}$
 Therefore, Peak amplitude of the output
 $= A + m_p = 3.414 \text{ kV}$
74. Dynamic range
 $= \frac{\text{Maximum opposite level}}{\text{Minimum opposite level}}$
 $= 20 \log \frac{300}{30 \times 10^{-3}}$
 $= 20 \log 10 \times 10^3 = 20 \log 10^4 = 20 \times 4$
 $= 80 \text{ dB}$
75. Minimum number of samples per second
 i.e., $f_s = 2 f_m = 2 \times 30 \text{ kHz} = 60,000$ samples/sec
 For 6-level PCM, 3 bits are required to represent each sample, so rate of digital signal generation.
 $= 3 \times 60,000$
 $= 180 \text{ kbps}$

CHAPTER 11

LEVEL 1

1. $\delta = \frac{2\pi}{\lambda} \times \frac{\lambda}{8} = \frac{\pi}{4}$
 $\bar{Z} = r + jk$
 and as $\delta < \pi/2$, x is negative (by the help of Smith Chart)
 so, $\bar{Z} = r - jk$
 Thus, load is a capacitive impedance.
2. For TE , $Z \uparrow$, $\lambda_g \uparrow$, $\alpha \uparrow$
 for TM , $Z \uparrow$, $\lambda_g \uparrow$, $\alpha \uparrow$
3. At microwave frequencies, a **varactor diode** are used
 A. For electronic tuning
 B. For frequency multiplication
 C. As a parametric
4. The correct sequence of the assembled parts in klystron amplifier from any end is cathode, buncher cavity, catcher cavity an anode.
7. Cross field amplifier (CFA) is a microwave power amplifier which is a case between the TWT and the magnetron in its operation and uses a magnetron structure to provide an interaction between crossed dc electric and magnetic field on one hand and RF fields on the other hand.
8. Broad banding a microwave transistor RF amplifier is difficult because of shunt capacitance loading effect.
9. Reflex klystron is widely used in the laboratory for microwave measurement and in microwave receiver as local oscillators in commercial, military, and airborne Doppler radar as well as missiles.
14. Reflex Klystron is widely used as an ideal local oscillator for microwave frequency measurement.
16. f_c will be doubled. Thus cut-off wavelength will be halved.
23. Microwave link repeaters are typically 50 km apart because of earth's curvature.
24. All practical TWT use some form of attenuator which has the subsidiary effect of reducing gain and subsequently preventing oscillations.
26. In an indirect transition, the energy is generally given up as heat to the lattice rather than as an emitted photon.
38. The helix is thought of as a special coaxial transmission line with large velocity per unit length. The inductance provide the coaxial circuit with a phase velocity much less than in free space. In fact, the input signal is slowed down to match the velocity of the electron beam heading toward the collector. As the beam and the input signal move together, they interact to produce velocity modulation of the electrons.
39. Gun diode can replace reflex klystron in receiver local oscillator, parametric amplifier pumps, signal generators, frequency modulated power oscillators, etc.
40. **Solution:** A micro-strip corresponds to a short length of flat coaxial cable, but in printed circuit form. Three factors determine the characteristic impedance of micro-strip. They are thickness of the substrate, the dielectric constant of the substrate and the width of the conducting strip.
44. $\rightarrow$ lowest cutoff frequency
 $\rightarrow$ longest cutoff wavelength
46. Microwave Link repeaters are used to compensate for the transmission loss in long-haul data communication. The repeating amplifier are inserted at regular intervals in order to maintain sufficient signal level. Their gain is just sufficient to compensate for the loss of signal levels between stations.
49. A duplexer is a circuit designed to allow the use of same antenna for both transmission and reception, with minimal interference between the transmitter and the receiver.
54. In one cycle rotation, the spoke goes through 2π radian shift
55. Bolo-meter contains a small resistive element which absorbs electromagnetic power. The resulting temperature is measured to give power absorbed.
57. Disoperation of heat generated by the amplifier
67. $T_d = \sqrt{\mu \epsilon} = 3.33 \sqrt{\epsilon_r} \text{ ns/m}$.
68. Phase velocity, $V_p = c \sqrt{1 - \left(\frac{f_c}{f}\right)^2}$
- Since phase velocity $V_p = \frac{v_1}{\sqrt{1 - (f_c/f)^2}}$
 it is seen that as f increases, v_p decreases.
69. Evanescent mode. The mode of oscillation in which the amplitude diminishes along a wave-guide without of phase.
70. Impulse response $= \frac{d}{dt} (1 - \alpha^{-at})$
 $= \alpha e^{-at}$
72. $E = \frac{\rho_s}{2\epsilon_o}$
 $= \frac{2 \times 10^{-9}}{2 \times 8.854 \times 10^{-12}} = -36 \pi a_z \text{ v/m}$.
74. $\lambda = \frac{3 \times 10^{10}}{2.5 \times 10^6} = 12 \text{ cm}$
 $\lambda_o = \frac{2a}{m} = 20 \text{ cm}$
 Since $+ = 0.8$, $\lambda_p = \frac{12}{0.8} = 15 \text{ cm}$.

LEVEL 2

1. The effective dielectric constant satisfies the relation, $1 < \epsilon_e < \frac{\epsilon + 1}{2}$
2. $P_{av} = \frac{1}{T} \int_0^{T_{ON}} 10^4 dt = 8\%$.
3. Required transform characteristic impedance
 $= Z_o = \sqrt{Z_s Z_L} = \sqrt{75 \times 300} = 50 \Omega$.

4. For Gun diode, Natural oscillation frequency

$$= \frac{\text{Drift velocity}}{\text{Active region length}} = \frac{10^7 \text{ cm/s}}{10 \times 10^{-4} \text{ cm}}$$

$$= 10^7 \times 10^3/\text{s} = 10^{10} \text{ Hz}$$

$$= 10 \times 10^9 \text{ Hz} = 10 \text{ GHz.}$$

5. $f_r = \frac{h \times c}{2\pi a}$; $a = \frac{D}{2}$

$$= \frac{2.4 \times 10^{-3} \times 10^8}{2\pi \times 12 \times 10^{-3}} = 9.57 \text{ GHz.}$$

6. $\lambda c = 2 \times 4.5 \text{ cm} = 9 \text{ cm.}$

7. TE_{10} is not possible in a circular waveguide.

8. $f = \frac{V_d}{2L} = \frac{10^5}{2 \times 4 \times 10^{-6}} = 12.5 \text{ GHz.}$

9. 3db loss = half power loss

$$50 \times \frac{1}{2} = 25.$$

10. Electric Field = $\frac{\text{voltage}}{\text{distance}}$

$$E = V/L; \quad V = E \times 2$$

$$\text{or, } V = 3.2 \times 10^3 \times 10^{-3} = 3.2 \text{ V.}$$

12. In a rectangular waveguide, for TM modes neither m or n can be 0. For TE modes, either m or n can be 0 but not both. And since $a > b$, so dominant mode would be TE_{10} .

14. $v_d = fL$

$$\text{or, } f = \frac{V_d}{L} = \frac{10^7}{10^{-3}} = 10 \text{ GHz}$$

15. The dominant circular waveguide mode is TE_{11} .

16. The device is a directional coupler as it is the s-matrix of a directional coupler.

37. $Q = \sin^{-1} \sqrt{\frac{1}{4}} = \sin^{-1} 0.5$

$$\text{Hence } \theta = 30^\circ.$$

39. Phase velocity

$$v_p = \frac{v_c}{\sqrt{\epsilon_r}} = \frac{3 \times 10^8}{\sqrt{4}} = 1.5 \times 10^8 \text{ m/s.}$$

40. Intrinsic impedance = $377 \sqrt{\frac{1}{4}} = 188 \Omega.$

44. $F(s) = H(s) \cdot E(s)$ convolution in time domain in multiplication in a domain

$$= \frac{10}{s+10} \times \frac{10}{s^2+100} = \frac{100}{(s+10)(s^2+100)}.$$

47. $R_x R(\tau) = \{V.V. \sin wt \sin w(t + \tau)\}$
 $= [V^2/2] E (\cos tw - \cos w(2t + \tau))$
 $= [V^2/2] \cos w\tau.$

48. $C = 4\pi\epsilon_o R$
 $= 4\pi\epsilon_o \times \frac{1}{4\pi\epsilon_o} = 1F.$

49. $Z_o = \sqrt{100 \times 64} = 80\Omega.$

50. $Z_{in} = \frac{Z_o^2}{Z_L} = \frac{(50)^2}{100} \Omega.$

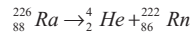
51. The phase of current in antenna A lags behind that of antenna B by $[\pi/2]$ radians.

57. $\lambda = \frac{2a}{m} = \frac{2a}{2} = a.$

59. $C = \frac{\epsilon_o \epsilon_r A}{d} = \frac{\epsilon_o \epsilon_r LW}{h}.$

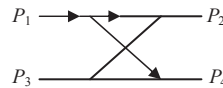
60. $Q = \frac{9 \times 10^9}{2.4 \times 10^6} = \frac{9000}{2.4}.$

65. An alpha particle is helium nucleus having atomic number 2 and mass number 4.



LEVEL 3

1.



$$\text{At input coupler, } C = 10 \log \left(\frac{P_1}{P_4} \right)$$

$$P_4 = 0.1 \text{ mW}$$

$$\therefore 40 = 10 \log \left(\frac{P_1}{0.1 \text{ m}} \right)$$

$$P_1 = 10^4 \times 0.1 \times 10^{-3} = 10 \text{ m}$$

$$P_1 \longrightarrow P_2$$

At output coupler

$$30 = 10 \log \left(\frac{P_1}{0.01 \times 10^{-3}} \right)$$

$$P_1 = 10^3 \times 0.01 \times 10^{-3} = 0.01$$

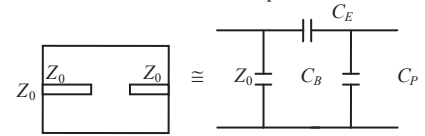
Insertion loss

$$I = 10 \log \frac{P_1}{P_2}$$

$$= 10 \log \frac{1}{0.01}$$

$$= 20 \text{ dB}$$

3. The equivalent circuit of a gap in the strip conductor of micro-strip is



5. In a rectangular waveguide, for TM modes neither m or n can be 0. For modes, either m or n can be 0 but not both. And since $a > b$, so dominant mode would be TE_{10} .

6. TE_{11} is the dominant mode of the circular waveguide.

9. A barrette is a short piece of fine wire with positive temperature coefficient of resistivity and enough total resistance, so that it can be matched to the system for efficient absorption of microwave energy

12. Property of Hybrid Tee $\rightarrow$ power fed to port (1) splits equally into Port (3) & Port (4) No power from Port (2) 4mW power fed to port t (1)

Therefore result is

Port (2) $\rightarrow$ 0

Port (3) $\rightarrow$ 2 mW

Port (4) $\rightarrow$ 2mW

Port (3) and Port 3' are same

For 2mW input at Port 3'

Port 1' $\rightarrow$ 1 mW

Port 2' $\rightarrow$ 1 mW

Port 4' $\rightarrow$ 0 mW

13. Directivity = $10 \log [P_4 / P_1]$

when matched

$$= 10 \log [0.1 / 100]$$

$$= -30 \text{ dB}$$

15. $f_c = \frac{X_{np}}{2\pi a \sqrt{\mu\epsilon}}$; $\lambda = \frac{C}{f} = C = \frac{1}{\sqrt{\mu\epsilon}}$

$$\text{or, } \lambda = \frac{2\pi a}{X_{np}} = \frac{\pi D}{X_{xp}}$$

$$= \frac{\pi D}{3.83} = 0.82D$$

$$f = 20 \text{ GHz; } \lambda = \frac{C}{f} = \frac{300 \times 10^6}{f \text{ MHz}} = \frac{300}{20}$$

$$= 15 \text{ mm}$$

$$\ell = \frac{\lambda}{2} = 15; \quad \beta = \frac{2\pi}{\lambda}; \quad \beta \ell = \frac{\lambda}{2} \times \frac{2\pi}{\lambda} = \pi.$$

16. $Z_{in} = Z_L \cdot \frac{R_L + jZ_L \tan \beta l}{Z_L + jR_L \tan \beta l}$

$$60 \times \frac{72}{60} = 72\Omega$$

Reflection coefficient and VSWR

When the load is not matched to the characteristic impedance of the line, then the wave is reflected back from Z_L .

Reflection coefficient for voltage

$$K = \left(\frac{Z_L - Z_o}{Z_L + Z_o} \right)$$

Then reflection coefficient

$$\text{Therefore, } |K| = \left| \frac{72 - 50}{72 + 50} \right| = \frac{22}{122}$$

$$VSWR = \frac{1 + |K|}{1 - |K|} = \frac{144}{100} = 1.44.$$

$$\begin{aligned} 17. \quad |K_L| &= |K_L| = \left| \frac{Z_L - Z_C}{Z_L + Z_C} \right| \\ &= \frac{40 + j30 - 50}{40 + j30 + 50} \\ &= \frac{-10 + j30}{90 + j30} = \frac{\sqrt{100 + 900}}{\sqrt{8100 + 900}} \\ &= \frac{\sqrt{1000}}{9000} = \sqrt{\frac{1}{9}} = \frac{1}{3} \end{aligned}$$

$$\therefore VSWR = \frac{1 + |K_L|}{1 - |K_L|} = \frac{1 + 1/3}{1 - 1/3} = \frac{4}{2} = 2.$$

$$18. \text{ For } TM_{mn}, E_z = E_0 \sin\left(\frac{m\pi}{a}x\right) \cdot \sin\left(\frac{n\pi}{b}y\right)$$

$$TM_{32}, E_z = 20 \sin(60\pi x) \sin(100\pi y).$$

Therefore, the lowest TM mode is TM_{11} .

$$\therefore \text{ for } TM_{11}, E_z = E_0 \sin(20\pi x) \cdot \sin(50\pi y).$$

19. For TE Mode

$$f_c = \frac{1}{2\sqrt{\mu\epsilon}} \cdot \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

given data is $a = a\sqrt{3}$; $b = a$

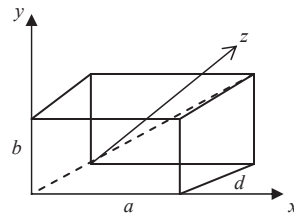
For TE_{10} Mode $m=1$, $n=0$

$$\begin{aligned} f_c &= \frac{1}{2\sqrt{\mu\epsilon}} \times \sqrt{\left(\frac{1}{a\sqrt{3}}\right)^2 + \left(\frac{0}{a}\right)^2} \\ &= \frac{1}{2a\sqrt{3}\sqrt{\mu\epsilon}} = 2 \text{ Ghz} \end{aligned}$$

For TM_{11} mode

$$\begin{aligned} f'_c &= \frac{1}{2\sqrt{\mu\epsilon}} \sqrt{\left(\frac{1}{a\sqrt{3}}\right)^2 + \left(\frac{1}{a}\right)^2} \\ &= \frac{1}{2a\sqrt{\mu\epsilon}} \sqrt{\frac{1}{3} + 1} = \frac{1}{2a\sqrt{\mu\epsilon}} \sqrt{\frac{4}{3}} \\ &= \frac{2}{2a\sqrt{3}\sqrt{\mu\epsilon}} = 2 \times 2 = 4 \text{ Ghz.} \end{aligned}$$

20.



Maxwell's wave equation is

$$\omega^2 \mu \epsilon = k^2 = -k_x^2 - k_y^2 - k_z^2$$

Resonant frequency or cavity

$$2pf_0 = \sqrt{[(k_x^2 + k_y^2 + k_z^2)/m\epsilon]}$$

$$f_0 = \frac{1}{2\pi\sqrt{\mu\epsilon}} \cdot \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{d}\right)^2}$$

$$k_x = \frac{m\pi}{a}, k_y = \frac{n\pi}{b}, k_z = \frac{p\pi}{d}$$

For $a > b < d$

Dominant mode is TE_{101}

Cut off frequency,

$$f_r = \frac{2}{(m/a)^2 + (n/b)^2 + (p/d)^2}$$

TE is the transverse electric mode for $a > b < d$, and is the dominant mode.

$$\begin{aligned} 21. \quad f_c &= \frac{1}{2\sqrt{\mu\epsilon}} \cdot \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \\ &= \frac{3 \times 10^{10}}{2} \cdot \sqrt{\left(\frac{1}{\sqrt{8}}\right)^2 + \left(\frac{1}{\sqrt{8}}\right)^2} \\ &= \frac{3 \times 10^{10}}{2} \times \frac{1}{2} = 7.5 \times 10^9 = 7.5 \text{ GHz.} \end{aligned}$$

22. Cut off frequency for rectangular wave guide (f_c)

$$\begin{aligned} f_c &= \frac{1}{2\sqrt{\mu\epsilon}} \cdot \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \\ &= \frac{3 \times 10^8}{2} \sqrt{\left(\frac{1}{2.29 \times 10^{-2}}\right)^2} \\ &= \frac{3 \times 10^8}{2 \times 2.29 \times 10^{-12}} = 6.55 \times 10^9 \text{ Hz} \\ &= 6.55 \times 10^9 \text{ Hz} \end{aligned}$$

$$TE_{10}, m=1$$

$$n=0$$

$$a = 2.29 \text{ cm}$$

$$b = 1.02 \text{ cm}$$

$$f = 11 \text{ GHz}$$

Potential Gradient

$$E = \left(\frac{V}{d} \right) = 5 \text{ Kc/cm}$$

$$\begin{aligned} \text{intrinsic Impedance } \eta_{TE_{10}} &= \frac{\eta_c}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}} \\ &= \frac{377}{\sqrt{1 - \left(\frac{6.55 \times 10^9}{11 \times 10^9}\right)^2}} \\ &= 469.2 \end{aligned}$$

$$\begin{aligned} \text{Power Handling in } TE_{10} \text{ mode} &= \frac{E_o^2}{4\eta} a \times b \\ &= \frac{(5 \times 10^3)^2}{4 \times 469.2} \times (2.29 \times 1.02) \\ &= 31.11 \text{ kW.} \end{aligned}$$

$$\begin{aligned} 23. \quad f_T &= \left(\frac{v_d}{2L} \right) \\ &= \frac{105}{2 \times 4 \times 10^{-6}} = 12.5 \text{ GHz.} \end{aligned}$$

$$\begin{aligned} 24. \quad A f_c &= \frac{C}{2} \sqrt{\frac{m^2}{a^2} + \frac{n^2}{b^2}} \\ f_c &= \frac{C}{2a} = \frac{3 \times 10^8}{2 \times 3 \times 10^{-12}} = 5 \text{ GHz.} \end{aligned}$$

25. Tunnel diode Application

1. Tunnel diode **amplifier** may be used throughout the microwave range as moderate-to-low-noise preamplifiers in all kinds of receivers.
2. Tunnel diode are diodes that may be used a **mixers**. Being also capable of active oscillation, they may be used as **self-excited mixers**.
3. Being high-speed devices, tunnel diodes also lend themselves to high-speed switching and logic operation, as flip-flops and gates.
4. They are used as **low-power oscillators** up to about 100 GHz, because of their simplicity, frequency stability and immunity to radiation.

CHAPTER 12

LEVEL 1

1. A crystal (or RC, LC network) is connected at these two points. The frequency of which is twice of the desired clock frequency.
2. The 8086 has instructions to add, subtract multiply and divide. It can operate on signed or unsigned binary numbers, BCD numbers, or numbers represented in ASCII.

4. The addressing modes described in the following section are used to specify the location of an operand in memory. To access data in memory, the 8086 must also produce a 20-bit physical address. It does this by adding a 16-bit value called the effective address to a segment base address represented by the 16-bit number in one of the four segment register. The effective address (EA) represents the displacement or offset of the desired operand from the segment base.
5. The 8085 has **six general purpose registers** to store 8 bit these are identified as *B, C, D, E, H, and L*. They can be combined as register pairs BC, DE, and HL—to perform some 16 bit operations. The programmer can use these registers to store or copy data into the registers by using data copy instructions.
7. A compiler reads entire program called a source code and then translates the program into the machine language, which is called an object code.
8. The **cache** in a system such as this consists of perhaps 32 or 64 Kbytes of high-speed SRAM. The main memory consists of a few megabytes or more of slower but cheaper DRAM. The general principal of a cache system is that code and data sections currently being used are copied from the DRAM of the high-speed SRAM cache, where they can be accessed by the processor with no wait states. A cache system takes advantage of the fact the most micro-computer programs work with only small section of code and data at a particular time. The fancy term for this is “locality of reference.” Here’s how the system works.

When the microprocessor output an address, the cache controller checks to see if the contents of that address have previously been transferred to the cache. If the addressed code or data word is present in the cache, the cache controller enables the cache memory to output the addressed word on the data bus. Since this access is to the fast SRAM, no wait states are required.

If the addressed word is not in the cache, the cache controller enables the DRAM controller. The DRAM controller then sends the address on to the main memory to get the data word. Since the DRAM main memory, it not only goes to the microprocessor, it is also written to the cache. If the processor needs to access this data word again, it can then read the data directly from the cache with no wait states. The percentage of accesses where the microprocessor finds the code or data word it needs in the cache is called the

hit rate. Current systems have average hit rates greater than 90 percent.

10. RISC

RISC stands for reduced instruction set computer. CISC stands for complex instruction set computer. There are two approaches of the design of the control unit of a microprocessor: hardware approach and software approach. To execute an instruction a number of steps are required. For each step a number of control signals are generated by the control unit of the processor. To execute each instruction, if there is a separate electronic circuitry in the control unit, which produces all the necessary signals, this approach. It is also called hard-wired approach. Microprogramming is not used. If the instruction are more, then this approach becomes complex. So RISC processor used a small number of simple instruction and a few addressing modes. They are faster than CISC processors. Each instruction is executed in one clock cycle. Most RISC instruction use register-to-register operations. Memory access is limited only to load and store instructions. For this purpose they employ a larger number of general-purpose registers. Large cache memory is used. Examples of RISC processors are DEC’s Alpha 21064, 21164 and 21264 processor, SUN’s SPARC and ULTRASPARC, PowerPC processors, etc.

15. X-OR gives output zero when both input are same which result all bit zero to after X-OR AA therefore zero flag is set.
16. **Based indexed Addressing**

8086 the operand’s offset is the sum of the content of a base register or BP and an index register SI or DI

$$\text{Offset} = [BX \text{ or } BP] + [SI \text{ or } DI]$$

BX is used as a base register for data segment, and BP is used as a base register for stack segment.

Examples are:

1. *ADD, AX [BX + SI]*
2. *MOV CX, [BX + SI]*.

17. Modem is used as an interface between analog and digital system. It is used to convert digital to analog signals and vice-versa.
20. In architecture of computer, Addressing modes, design of CPU, instruction set and data format are the part of it.
21. First machine cycle of an instruction is always a fetch cycle.
22. *S - Sign*: The Sign flag is set if bit D_7 of the result = 1 : otherwise it is reset.

23. Microprocessor acknowledges interrupt through $\overline{\text{INTA}}$ and wait for the next instruction from the interrupting device.
25. PROM has fixed AND array and a programmable ‘OR’ array.
28. Following statements are correct i.e. cache memory is fast but costly memory and performance of cache during program execution is measured by hit ratio.

30. Logic families comparison

Logic	Gate	Fan-out	Power loss mW	Noise	Propagation n sec
RTL	NOR	5	12	N	12
DTL	NAND	8	8	G	30
HTL			50	E	
TTL	NAND	10	12	VG	12
ECL	NOR/ OR	25	40	G	4
MOS	NAND	20	0.2	N	V
CMO	NOR/ NAND	50	0.01	V	70

*N → Normal *S → Satisfactory

*G → Good *VG → Very good

*E → Excellent

*Bipolar devices are faster and i.e. current controlled device as $I_c = \beta I_b$. Whereas MOS device require less area and consume less power due to high input impedance.

LEVEL 2

3. Effective memory address, (i.e., 20 bit physical address),

$$\begin{array}{r} I \quad F \quad A \quad B \quad 0 \quad H \\ + \quad 1 \quad 0 \quad A \quad 1 \quad H \\ \hline 2 \quad 0 \quad B \quad 5 \quad 1 \quad H \end{array}$$

4. It will need 8 clock pulses.
Therefore $T = 8 \times T_0 = 8 \mu\text{s}$.
5. Number of pins = 16 addressing line (64 K)
+ 8 data line (byte)
+ 1 (CE)
+ 1 ($\overline{RD/\overline{WR}}$)
+ 1 (S_0)
+ 1 (S_1)
= 28.

7. $AX \rightarrow c$; $BX \rightarrow b$
 SUB $AX, BX \rightarrow c - b$
 $BX \rightarrow a$
 ADD $AX, BX \rightarrow a + c - b$ $c - b + a$.

9. **Memory Mapped I/O**

In this some portion of the available memory address space is reserved for input/output devices, while the rest is for

RAM/ROM. One major advantage is that *all the instruction types including arithmetic and logic operation as also the different addressing modes are available to I/O data transfer* in contrast to just two, IN and OUT, instructions of isolated I/O. Also data from any register can be moved to a port or data from a port to moved to any register. In Isolated I/O mode data to

and from ports have be routed through the Accumulator.

21. The number of bits in which two code words differ is know as the Hamming distance. In this case, only alternative with a Hamming distance of exactly 2 is option (b).
24. $2^{16} = 64\ k$.

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TEST PAPERS

TEST PAPER 1

1. Which of the following statements is/are true for the diamond structure?
 1. Coordination number is four.
 2. Packing fraction is 0.34.
 3. Copper crystallizes into diamond structure
 4. Lattice is FCC

(a) 1 only (b) 1, 2 and 4
(c) 2 and 3 only (d) 2, 3 and 4
2. Which of the following statements is/are true for a good conductor of electricity?
 1. Its conductivity decreases with increasing temperature.
 2. Number of free electrons is around 10^{28}m^{-3} .
 3. Its conductivity decreases with addition of impurities.
 4. It is a good conductor of heat also.

(a) 1, 2, 3 and 4 (b) 1 only
(c) 2 and 3 only (d) 3 and 4 only
3. Which of the following materials is not an insulator?

(a) Diamond (b) Graphite
(c) Bakelite (d) Lucite
4. Consider the following statements:
The conductivity of a metal has negative temperature coefficient since:
 1. The electron concentration increases with temperature
 2. The electron mobility decreases with temperature.
 3. The electron lattice scattering rate increases with temperatureWhich of the above statements is/are correct?

(a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 3 only
5. Which of the following is not a conducting material?

(a) Copper (b) Tungsten
(c) Germanium (d) Platinum
6. What is the chemical bonding in silicon semiconductor?

(a) Metallic (b) Ionic
(c) Covalent (d) Van der waals
7. Which one of the following is a trivalent material?

(a) Antimony (b) Phosphorus
(c) Arsenic (d) Boron
8. The fuse material used in electrical lines must have which one of the following properties?

(a) High resistivity (b) Low conductivity
(c) High melting point (d) Low melting point
9. Manganin, an alloy of copper and manganese, is used in

(a) Soldering material (b) Heating elements
(c) Ballast resistors (d) Standard resistance
10. Which one of the following pairs is not correctly matched?

(a) NaCl : Diamagnetic
(b) Gd : Paramagnetic
(c) Ferrite : Ferrimagnetic
(d) Cr_2O_3 : Ferromagnetic
11. Hysteresis loss in a transformer working at 220 V and at a frequency of 50 Hz is 100 W. When the transformer is operated at 220 and at a frequency of 100 Hz, what is the hysteresis loss?

(a) 50 W (b) 100 W
(c) 200 W (d) 400 W

13.2 ■ Test Papers

12. Which of the following is not electromagnetic device?
 (a) Hall transducer
 (b) Transformer
 (c) Speedometer
 (d) Eddy current damping device
13. Which one of the following materials is used for making permanent magnets?
 (a) Steel (b) Carbon
 (c) Carbon steel (d) Graphite
14. What happens when a paramagnetic material is heated above Curie temperature?
 (a) It becomes diamagnetic
 (b) It becomes non magnetic
 (c) It becomes ferromagnetic
 (d) It becomes anti ferromagnetic.
15. Ferromagnetic materials show hysteresis in B - H characteristic. As the magnetic field is increased slowly from zero value, what is the first process which sets in the material to give net magnetization?
 (a) Growth of favourably oriented domains at the cost of other domains by reversible boundary displacements.
 (b) Growth of favourably oriented domains at the cost of other domains by irreversible boundary displacements
 (c) Domain wall orientation
 (d) A combination of processes (a) and (c) above.
16. The following properties are associated with ferroelectric materials:
 1. Its susceptibility is negative.
 2. The susceptibility is expressed as $\chi = \frac{c}{T - T_c}$ where c is the Curie constant and T_c is the Curie temperature.
 3. It has permanent dipoles oriented randomly.
 Which of the above statements is/are correct?
 (a) 1 only (b) 1 and 3
 (c) 2 only (d) 1, 2 and 3
17. Consider the following:
 1. Si 2. Ge
 3. GaAs 4. InP
 Which of the above semiconductors should be used for making highly efficient photodiodes?
 (a) 1 and 4 only (b) 3 and 4 only
 (c) 1, 3 and 4 (d) 2, 3 and 4
18. The materials not having negative temperature coefficient of resistivity are
 (a) Metals (b) Semiconductors
 (c) Insulators (d) None of the above
19. Which one of the following compounds is widely used for making ferrites?
 (a) FeO (b) CuO
 (c) MgO (d) Fe_2O_3
20. Effective Q of the equivalent electrical circuit of quartz crystal is of the order of
 (a) 200 (b) 2000
 (c) 20, 000 (d) 2, 00, 000
21. In a material the Fermi level is located between the centre of the forbidden band and the conduction band. Then what is that material?
 (a) A p-type semiconductor
 (b) An n type semiconductor
 (c) An intrinsic semiconductor
 (d) An insulator
22. Consider the following statements:
 1. Acceptor level is formed very close to the conduction band.
 2. The effective mass of the free electron is same as that of a hole.
 3. The magnitude of the charge of a free electron is same as that of a hole.
 4. Addition of donor impurities adds holes to the semiconductor.
 Which of the above statements are correct?
 (a) 1 and 3 (b) 2 and 3
 (c) 2 and 4 (d) 3 and 4
23. Diffusion current of holes in a semiconductor is proportional to (with p = concentration of holes/unit volume).
 (a) $\frac{dp}{dx^2}$ (b) $\frac{dp}{dx}$
 (c) $\frac{dp}{dt}$ (d) $\frac{d^2p}{dx^2}$
24. The junction capacitance of a linearly graded pn junction (with applied voltage = VB) is proportional to
 (a) $V_B^{-\frac{1}{2}}$ (b) $V_B^{-\frac{1}{2}}$
 (c) $V_B^{-\frac{1}{3}}$ (d) $V_B^{-\frac{1}{3}}$
25. As per Hall effect, if any specimen carrying a current I is placed in a transverse magnetic field B, then an electric field E is induced in the specimen in the direction.
 (a) parallel to I
 (b) perpendicular to B and parallel to I
 (c) parallel to I and B
 (d) perpendicular to both I and B.
26. What current does

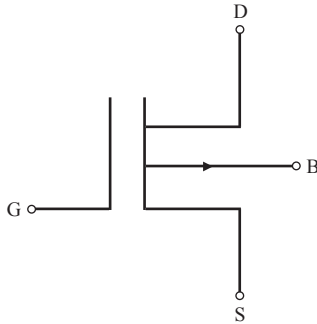
$$I = Aq \left(\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A} \right) n_i^2$$
 represent in pn junction diode?
 (where the symbols have their usual meaning).
 (a) Forward current
 (b) Diffusion current
 (c) Drift current
 (d) Reverse saturation current
27. Which of the following quantities can not be measured / determined using hall effect?
 (a) Type of semiconductor (p or n)
 (b) Mobility of charge carriers

- (c) Diffusion constant
(d) Carrier concentration.

28. A junction FET can be used as a voltage variable resistor.

- (a) at pinch off condition
(b) beyond pinch off voltage
(c) well below pinch off condition
(d) for any value of V_{DS}

29. The below figure shows the symbol of



- (a) p channel depletion MOSFET
(b) p channel enhancement MOSFET
(c) complementary MOSFET
(d) p channel JFET

30. The maximum power dissipation capacity of a transistor is 50 mW. If the collector emitter voltage is 10 V, what is the safe collector current that can be allowed through the transistor?

- (a) 5 mA (b) 2.5 mA
(c) 10 mA (d) 25 mA

31. Which one of following statements is correct for MOSFETS?

- (a) p channel MOS is easier to produce than n channel MOS
(b) n channel MOS must have twice the area of p channel MOS for the same ON resistance
(c) p channel MOS has faster switching action than n channel MOS
(d) p channel MOS has higher packing density than n channel MOS

32. The process of extension of a single-crystal surface by growing a film is such a way that the added atoms form a continuation of the single-crystal is called.

- (a) Ion implantation
(b) Chemical vapour deposition
(c) Electroplating
(d) Epitaxy

33. The maximum concentration of the element which can be dissolved in solid silicon at a given temperature is termed as

- (a) Solid solubility
(b) Dissolution coefficients
(c) Solidification index
(d) Concentration index

34. Which of the following devices is used in the microprocessors?

- (a) JFET (b) BJT
(c) MOSFET (d) CMOS

35. In a CMOS CS amplifier, the active load is obtained by connecting a

- (a) p channel current mirror circuit
(b) n channel transistor
(c) p channel transistor
(d) BJT current mirror

36. Which one of the following is not LED materials?

- (a) GaAs (b) GaP
(c) SiC (d) SiO₂

37. The minimum energy of a photon required for intrinsic excitation is equal to

- (a) Energy of bottom of conduction band
(b) Energy of top of valence band
(c) Forbidden gap energy
(d) Fermi energy

38. A signal $x_1(t)$ and $x_2(t)$ constitute the real and imaginary parts respectively of a complex valued signal $x(t)$. What form of waveform does $x(t)$ possess?

- (a) Real symmetric (b) Complex symmetric
(c) Asymmetric (d) Conjugate symmetric

39. A function of one or more variables which conveys information on the nature of physical phenomenon is called

- (a) Noise (b) Interference
(c) System (d) Signal

40. The output $y(t)$ of a continuous time system S for the input x is given by

$$y(t) = \int_{-\infty}^t x(\lambda) d\lambda$$

Which one of the following is correct?

- (a) S is linear and time invariant
(b) S is linear and time varying
(c) S is non linear and time invariant
(d) S is non linear and time varying

41. What is the period of the sinusoidal signal $x(n) = 5 \cos [0.2\pi n]$?

- (a) 10 (b) 5
(c) 1 (d) 0

42. Transfer function of a certain system is

$$\frac{Y(s)}{U(s)} = \frac{1}{s^4 + 5s^3 + 8s^2 + 6s + 3}$$

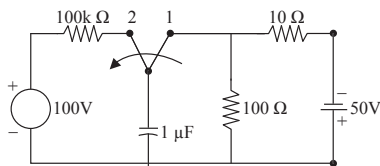
Which one of the following will be the A, B matrix pair of state variable representation of this system?

- (a)
$$\begin{bmatrix} -0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 3 & -6 & -8 & -5 \end{bmatrix} \quad \begin{bmatrix} -0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

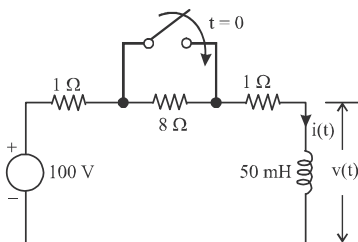
(b)
$$\begin{bmatrix} -0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 5 & -8 & -6 & -3 \end{bmatrix} \quad \begin{bmatrix} -0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

$$\begin{array}{ccccc}
 -1 & 0 & 0 & 0 & -1 \\
 0 & 1 & 0 & 0 & 0 \\
 (c) & 0 & 0 & 1 & 0 \\
 \equiv 3 & -6 & -8 & -5 & \equiv 0 \\
 -0 & 1 & 0 & 0 & -1 \\
 (d) & 0 & 0 & 1 & 0 \\
 0 & 0 & 0 & 1 & 0 \\
 \equiv 3 & -6 & -8 & -5 & \equiv 0
 \end{array}$$

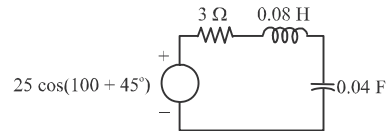
43. Separation property of state transition matrix is
 (a) $\phi(t-t_0) = \phi(t)\phi(t_0)$ (b) $\phi(t-t_0) = \phi^{-1}(t)\phi^{-1}(t_0)$
 (c) $\phi(t-t_0) = \phi(t)\phi^{-1}(t_0)$ (d) $\phi(t-t_0) = \phi^{-1}(t)\phi^{-1}(t_0)$
44. When $y(t) \xrightarrow{FT} Y(j\omega)$; $x(t) \xrightarrow{FT} X(j\omega)$;
 $h(t) \xrightarrow{FT} H(j\omega)$. What is $Y(j\omega)$
 (a) $\frac{X(j\omega)}{H(j\omega)}$ (b) $X(j\omega)H(j\omega)$
 (c) $X(j\omega) + H(j\omega)$ (d) $X(j\omega) - H(j\omega)$
45. For a series R-L-C circuit, the characteristic equation is given as
 $s^2 + \frac{R}{L}s + \frac{1}{LC} = 0$
 If $\frac{R}{2L}$ is denoted by α and $\frac{1}{\sqrt{LC}}$ by β , then under the condition of $\beta^2 > \alpha^2$, the system will be
 (a) Critically damped (b) under damped
 (c) undamped (d) over damped
46. In the below circuit, the switch has been in position 1 for quite a long time. At $t = 0$ the switch is moved to position 2. At this position, what is the time constant?



- (a) 0.1s (b) 1s
 (c) 0.11s (d) 1.11s
47. In the below circuit, the switch is open for a long time. At time $t = 0$, the switch is closed. What are the initial and final values of voltages across the inductor?



- (a) 0 V and 0 V (b) 0 V and 80 V
 (c) 80 V and 0 V (d) 80 V and 80 V
48. The voltage applied to an R - L circuit at $t = 0$ when switch is closed is $100 \cos(100t + 30^\circ)$. The circuit resistance is 80Ω and inductance is 0.6 H (in which initial current is zero). What is the maximum amplitude of current flowing through the circuit?
 (a) 1 A (b) 2 A
 (c) 5 A (d) 10 A
49. A series R - C circuit with $R = 3\Omega$ and $X_c = 4\Omega$ at 50 Hz is supplied with a voltage $V = 50 + 141.4 \sin 3.14 t$. What is the RMS value of the current flowing through the circuit?
 (a) 5 A (b) 10 A
 (c) 20 A (d) 22.36 A
50. What is the approximate steady state current in the below circuit?



- (a) 50 A (b) 25 A
 (c) 5 A (d) 1 A
51. Consider the following statements regarding the properties of an R-L-C series circuit under resonance:
 1. Current in the circuit is in phase with applied voltage.
 2. Voltage drop across capacitor C and inductance L are equal in magnitude.
 3. Voltage across the capacitor is equal in magnitude to the applied voltage.
 4. Current in the circuit is maximum.
 Which of the above statements is are correct?
 (a) 1 only (b) 1, 2 and 4
 (c) 2 and 4 (d) 1, 3 and 4
52. Which one of the following is applicable to any network, linear or non-linear, active or passive, time varying or invariant as long as Kirchhoff's laws are not violated?
 (a) Tellegen's theorem
 (b) Reciprocity theorem
 (c) Maximum power transfer theorem
 (d) Superposition theorem
53. Number of fundamental cut sets of any graph will be
 (a) Same as the number of twigs
 (b) Same as the number of tree branches
 (c) Same as the number of nodes
 (d) Equal to one
54. If in an electric network R, L and C are connected in series and supplied by a voltage source then its dual network will be described by the differential equation

$$\begin{array}{l}
 (a) \quad v(t) = Ri(t) + L \frac{di(t)}{dt} + \frac{1}{C} \int i(t) dt \\
 (b) \quad v(t) = \frac{1}{G} i(t) + C \frac{di(t)}{dt} + \frac{1}{L} \int i(t) dt
 \end{array}$$

$$(c) \quad i(t) = G v(t) + C \frac{dv(t)}{dt} + \frac{1}{L} \int v(t) dt$$

$$(d) \quad v(t) = Ri(t) + L \frac{di(t)}{dt} + C \int i(t) dt$$

55. In a network with twelve circuit elements and five nodes, what is the minimum number of mesh equations?
- (a) 24 (b) 12
(c) 10 (d) 8
56. With respect to transmission parameters, which one of the following is correct?
- (a) A and B are dimensionless
(b) B and C are dimensionless
(c) A and D are dimensionless
(d) B and D are dimensionless
57. Match list I with list II and select the correct answer using the code given below the lists:

List I**(Network Parameters)**(a) Z_{11}

(b) A

(c) C

(d) Z_{22} **List II****(Measured under open circuit Conditions)**

1. $\left. \frac{V_2}{I_2} \right|_{I_1=0}$

2. $\left. \frac{V_1}{I_2} \right|_{I_2=0}$

3. $\left. \frac{V_1}{I_1} \right|_{I_2=0}$

4. $\left. \frac{I_1}{V_2} \right|_{I_2=0}$

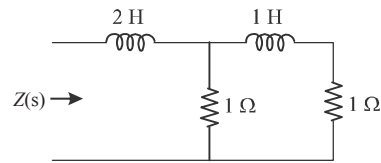
Codes:

	A	B	C	D
(a)	1	4	2	3
(b)	3	4	2	1
(c)	1	2	4	3
(d)	3	2	4	1

58. Which one of the following driving point function does not represent an LC network?
- (a) $Z(s) = \frac{s(s+3)}{(s^2+1)(s^2+9)}$
- (b) $Z(s) = \frac{(s^2+25)}{s(s^2+36)}$
- (c) $Z(s) = \frac{(s^2+1)(s^2+36)}{s(s^2+4)(s^2+25)}$
- (d) $Z(s) = \frac{s(s^2+16)}{(s^2+25)}$
59. If a two port network is reciprocal as well symmetrical, which one of the following relationships is correct?

- (a) $Z_{12} = Z_{21}$ and $Z_{11} = Z_{22}$
(b) $Y_{12} = Y_{21}$ and $Y_{11} = Y_{22}$
(c) $AD - BC = 1$ and $A=D$
(d) All of the above

60. If the connection of two-ports is such that the transmission matrix of the over all network is the product of the transmission matrices of the individual networks what type of connection is it?
- (a) Series connection (b) Cascade connection
(c) Parallel connection (d) None of the above
61. Consider the below network. Impedance of this network as a function of the complex frequency consists of a certain number of zeros and poles. What is the location of poles?



- (a) -2 (b) -2, ∞
(c) 2 (d) 2, ∞
62. Consider the following network function
- $$N(s) = \frac{s(s+2)}{(s+4)(s+1+j1)(s+1-j1)}$$
- In order to make $N(s)$ as rational network function, it is essential to include
- (a) Zero at origin (b) Zero at infinity
(c) Pole at origin (d) Pole at infinity
63. For determining the network function of a two port network, it is required to consider that
- (a) all initial conditions remain same
(b) all initial conditions are zero
(c) part of initial conditions are equal to zero
(d) initial conditions vary depending on nature of network
64. All poles and zeros of a driving point immittance function of an L - C network.
- (a) should lie on the $j\omega$ axis
(b) should lie on the +ve real axis
(c) should lie on the -ve real axis
(d) can lie anywhere in s plane
65. In the field of a charge Q at the origin, the potentials at A (2, 0, 0) and B (1/2, 0, 0) are $V_A = 15$ volt and $V_B = 30$ volt respectively. What will be the potential at C (1, 0, 0)?
- (a) 25 volt (b) 22.5 volt
(c) 20 volt (d) 11.7 volt
66. What will be the equipotential surfaces for a pair of equal and opposite line charges?
- (a) Spheres
(b) Concentric cylinders
(c) Non concentric cylinders
(d) None of the above

67. If the potential functions V_1 and V_2 satisfy Laplace's equation within a closed region and assume the same values on its surface, then which of the following is correct?
- V_1 and V_2 are identical
 - V_1 is inversely proportional to V_2
 - V_1 has the same direction as V_2
 - V_1 has the same magnitude as V_2 but has different direction.
68. If $V = \sinh x \cdot \cos ky \cdot \exp z$ is a solution of Laplace's equation, what will be the value of k ?
- $\frac{1}{\sqrt{1+p^2}}$
 - $\sqrt{1+p^2}$
 - $\frac{1}{\sqrt{1-p^2}}$
 - $\sqrt{1-p^2}$
69. By what name is the equation $\nabla \cdot \vec{J} = 0$ frequently known?
- Poisson's equation
 - Laplace's equation
 - Continuity equation for steady currents
 - Displacement equation.
70. Method of images is applicable to which fields?
- Electrostatic fields only
 - Electrodynamic fields only
 - Neither electrostatic fields nor electrodynamic fields
 - Both electrostatic fields and electrodynamic fields
71. Who developed the concept of time varying electric field producing a magnetic field?
- Gauss
 - Faraday
 - Hertz
 - Maxwell
72. A single turn loop is situated in air, with a uniform magnetic field normal to its plane. The area of the loop is 5 m² and the rate of change of flux density is 2 Wb / m² / s. What is the emf appearing at the terminals of the loop?
- 5 V
 - 2 V
 - 0.4 V
 - 0 V
73. Which of the following equations results from the circuital form of Ampere's law?
- $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
 - $\nabla \cdot \vec{B} = 0$
 - $\nabla \cdot \vec{D} = \rho$
 - $\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$
74. In which direction is the plane wave $\vec{E} = 50 \sin(10^8 t + 2z) \hat{a}_y$ V/m, (where $\hat{a}_y$ is the unit vector in y - direction), travelling?
- along y direction
 - along -y direction
 - along z direction
 - along -z direction
75. For parallel plane waveguides, which is the mode with lowest cut off frequency?
- TE_{10}
 - TM_{10}
 - TEM
 - TE_{11}
76. For plane wave propagating in free space or two conductor transmission line, what must be the relationship between the phase velocity v_p , the group velocity v_g and speed of light c ?
- $v_p > c > v_g$
 - $v_p < c < v_g$
 - $v_p = c = v_g$
 - $v_p < c < v_g$
77. The reflection coefficient on a 500 m long transmission line has a phase angle of -150° . If the operating wavelength is 150 m. What will be the number of voltage maxima on the line?
- 0
 - 3
 - 6
 - 7
78. Consider the following statements:
For a 10 m long common power line connecting a switch to a light bulb
- It is a distributed circuit.
 - Time delay for propagation through it is negligible
 - It is in the form of a shielded coaxial cable of circular cross section.
 - As the intensity of the lamp varies, input impedance of this line also changes.
- Which of the above statements are correct?
- 1 only
 - 1 and 2
 - 2 and 3
 - 2 and 4
79. With regard to a transmission line, which of the following statements is correct?
- Any impedance repeats itself every $\lambda/4$ on the smith chart.
 - The S.W.R. = 2 circle and the magnitude of reflection coefficient = 0.5 circle coincide on the smith chart.
 - At any point on a transmission line, the current reflection coefficient is the reciprocal of the voltage reflection coefficient.
 - Matching eliminates the reflected wave between the source and the matching device location.
80. Consider the following statements:
In a microstrip line
- Wavelength $= \frac{\lambda}{\epsilon_{eff}}$ where ϵ_{eff} is the effective dielectric constant and λ is the free space wavelength.
 - Electromagnetic fields exist partly in the air above the dielectric substrate and partly within the substrate itself
 - The effective constant dielectric constant is greater than the dielectric constant of the air.
 - Conductor losses increase with decreasing characteristic impedance.
- Which of the above statements are correct?
- 1, 2 and 3
 - 1 and 2 only
 - 2, 3 and 4
 - 4 only
81. It is required to match a 200 Ω load to a 450 Ω transmission line. To reduce the SWR along the line to 1, what must be the characteristic impedance of the quarter wave transformer used for this purpose, if it is connected directly to the load?

- (a) $90\text{ k}\Omega$ (b) $300\ \Omega$
 (c) $\frac{9}{4}\ \Omega$ (d) $\frac{3}{2}\ \Omega$

82. The load end of a quarter wave transformer gets disconnected thereby causing an open circuited load. What will be the input impedance of the transformer?

- (a) Zero (b) Infinite
 (c) Finite and positive (d) Finite and Negative

83. Match list I with list II and select the correct answer using the code given below the lists:

List I (Type of trans mission structure)	List II (Modes of propagation)

A. Strip line	1. Quasi TEM
B. Hollow rectangular waveguide	2. Pure TEM
C. Microstrip	3. TE / TM
D. Corrugated waveguide	4. Hybrid

Codes:

	A	B	C	D
(a)	2	1	3	4
(b)	4	1	3	2
(c)	2	3	1	4
(d)	4	3	1	2

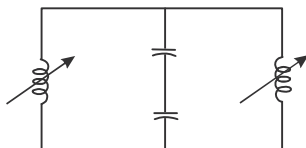
84. A standard waveguide WR90 has inside wall dimensions of $a = 2.286\text{ cm}$ and $b = 1.016\text{ cm}$. What is the cut off wavelength for TE₀₁ mode?

- (a) 4.572 cm (b) 2.286 cm
 (c) 2.032 cm (d) 1.857 cm

85. When a particular mode is excited in a waveguide, there appears an extra electric component, in the direction of propagation. In what mode is the wave propagating?

- (a) Transverse electric
 (b) Transverse magnetic
 (c) Transverse electromagnetic
 (d) Longitudinal

86. The below shown circuit is the equivalent circuit of which one of the following microwave resonator types?



- (a) Butterfly resonator
 (b) Parallel wire resonator
 (c) Cavity resonator
 (d) Coaxial line resonator

87. Which is the dominant mode in rectangular waveguides?

- (a) TE_{10} (b) TE_{11}
 (c) TM_{01} (d) TM_{11}

88. Consider the following statements:

For a square waveguide of cross section $3\text{ m} \times 3\text{ m}$ it has been found

- At 6 GHz dominant mode will propagate.
- At 4 GHz all the modes are evanescent.
- At 11 GHz only dominant modes and no higher order mode will propagate.
- At 7 GHz degenerate modes will propagate.

Which of the above statements are correct?

- (a) 1 and 2 only
 (b) 1, 2 and 4
 (c) 2 and 3 only
 (d) 2, 3 and 4

89. Match list I with list II and select the correct answer using the code given below the lists:

List I (Modes)	List II (Characteristic)
A. Evanescent mode	1. Rectangular waveguide does not support
B. Dominant mode	2. No wave propagation
C. TE_{10} and TE_{01}	3. Lowest cut off frequency

Codes:

	A	B	C
(a)	1	2	3
(b)	2	3	1
(c)	1	3	2
(d)	2	1	3

90. Multiple member of antennas are arranged in arrays in order to enhance what property?

- (a) Both directivity and bandwidth
 (b) Only directivity
 (c) Only bandwidth
 (d) Neither directivity nor bandwidth.

91. Consider the following statements regarding an antenna:

- It is a transducer.
- Its performance is essentially frequency sensitive
- It is a reciprocal device.
- With increase in its effective aperture area, width of the radiated beam increases.

Which of the above statements are correct?

- (a) 1, 2 and 3 (b) 1, 2 and 4
 (c) 2 and 3 only (d) 1 and 4 only

92. What is the minimum value of VSWR that may exist on a transmission line?

- (a) Less than zero (b) Zero
 (c) One (d) 10

93. For a second order instrument, the optimum range of ζ (damping ratio), which gives good frequency response over a wide range of frequencies is

- (a) 0.5 to 0.6 (b) 0.6 to 0.7
 (c) 0.7 to 0.8 (d) 0.8 to 1.0

94. The Wheatstone bridge method of measuring resistance is ideally suited for the measurement of resistance values in the range of
 (a) 0.001 to 1 Ω (b) 0.1 to 100 Ω
 (c) 100 Ω to 10 k Ω (d) 100 k Ω to 10 M Ω
95. What is the major cause of creeping in an energy meter?
 (a) Over compensation for friction
 (b) Mechanical vibrations
 (c) Excessive voltage across the potential coil
 (d) Stray magnetic fields.
96. A compensated wattmeter has its reading corrected for error due to which one of the following parameters?
 (a) Frequency
 (b) Friction
 (c) Power consumed in current coil
 (d) power consumed in pressure coil.
97. Which one of the following bridges is also used in an oscillator?
 (a) Maxwell (b) Schering
 (c) Hay (d) Wien
98. Which of the following meters cannot measure a.c. quantities?
 (a) Thermocouple (b) Hot wire
 (c) P. M. M. C. (d) Electrodynamometer
99. Which of the following meters requires an external power source for its operation?
 (a) P. M. M. C. meter (b) Hot wire ammeter
 (c) Electronic voltmeter (d) Electrodynamometer
100. Which of the following statements is not correct for thermistors?
 (a) They have negative temperature coefficient of resistance.
 (b) The sensing element is made of sintered ceramics, which are oxides of metals in the form of beads.
 (c) The variation of resistance with temperature is linear.
 (d) The resistance value at ambient temperature may range from 100 Ω to 100 k Ω .

ANSWER KEYS

1. (b)	2. (a)	3. (b)	4. (c)	5. (c)	6. (c)	7. (d)	8. (d)	9. (d)	10. (b)
11. (a)	12. (a)	13. (c)	14. (a)	15. (d)	16. (c)	17. (b)	18. (a)	19. (d)	20. (c)
21. (b)	22. (b)	23. (b)	24. (d)	25. (d)	26. (d)	27. (c)	28. (c)	29. (a)	30. (b)
31. (a)	32. (d)	33. (b)	34. (d)	35. (a)	36. (d)	37. (c)	38. (d)	39. (d)	40. (a)
41. (a)	42. (b)	43. (c)	44. (b)	45. (b)	46. (a)	47. (c)	48. (a)	49. (c)	50. (c)
51. (b)	52. (a)	53. (a)	54. (c)	55. (d)	56. (c)	57. (d)	58. (a)	59. (d)	60. (b)
61. (b)	62. (b)	63. (b)	64. (a)	65. (b)	66. (c)	67. (a)	68. (d)	69. (c)	70. (a)
71. (d)	72. (a)	73. (d)	74. (d)	75. (a)	76. (c)	77. (c)	78. (c)	79. (c)	80. (a)
81. (b)	82. (a)	83. (c)	84. (c)	85. (b)	86. (a)	87. (a)	88. (a)	89. (b)	90. (b)
91. (a)	92. (c)	93. (a)	94. (c)	95. (a)	96. (d)	97. (d)	98. (c)	99. (c)	100. (c)

TEST PAPER 2

1. Consider the following statements:

The thermal noise power generated by a resistor is proportional to

1. The value of the resistor
2. The absolute temperature.
3. The bandwidth over which it is measured.
4. The Boltzmann's constant.

Which of the above statements is /are correct?

- (a) 1, 2 and 3 (b) 2 only
(c) 2 and 3 only (d) 2, 3 and 4

2. Consider the following statements:

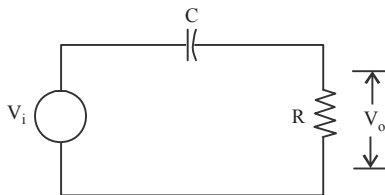
1. The output unit of a computer communicate the response of the computer to the user.
2. Read/write memory is volatile.
3. The flip-flops in a register are connected in parallel.

Which of the above statements is/are correct?

- (a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 3 only

3. In the below shown circuit, under what conditions the output

V_o will be proportional to $\frac{dv_i}{dt}$
(with T = time period of input)



- (a) $RC = T$ (b) $RC \gg T$
(c) $RC \ll T$ (d) Both R and C large

4. Transient stability of a 3-phase power systems having more than one synchronous generator is not affected by which one of the following specifications?

- (a) Initial operating condition of generators
- (b) Quantum of large power disturbance
- (c) Fast fault clearance and redressure
- (d) Small changes in system frequency

5. Consider the following:

1. L.P.F. method
2. E.M.F. method
3. Z.P.F. method
4. M.M.F. method

Which one of the above methods are correct for determination of voltage regulation of an alternator?

- (a) 1, 2 and 3 (b) 2, 3 and 4
(c) 2 and 3 only (d) 3 and 4 only

6. Match list I with list II and select the correct answer using the code given below the lists:

List I

(Machine components)

- A. Amortisseur winding
B. Breather
C. End-Rings
D. Commutator

List II

(Type of Machine)

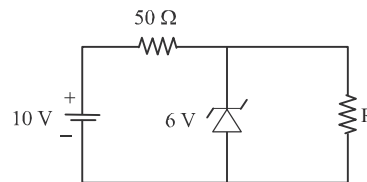
1. Squirrel cage induction motor
2. D.C. motor
3. Transformer
4. Synchronous motor

A	B	C	D
(a) 2	3	1	4
(b) 4	3	1	2
(c) 2	1	3	4
(d) 4	1	3	2

7. The maximum demand of a consumer is 2kW and the corresponding daily energy consumption is 30 units. What is the corresponding load factor?

- (a) 25% (b) 50%
(c) 62.5% (d) 75%

8. The 6 V zener diode as shown in the circuit below, has zero zener resistance and a knee current of 5 mA. Then what is the minimum value of R so that the voltage across it does not fall below 6 V?



- (a) 1200 ohms (b) 80 ohms
(c) 50 ohms (d) 40 ohms

9. When the operand requires for an instruction is stored inside the processor, then what this address mode is called?

- (a) Direct (b) Register
(c) Implicit (d) Immediate

10. How much power will an AM transmitter, rated at 50 kW, radiate if it is modulated to 100%?

- (a) 25 kW (b) 50 kW
(c) 75 kW (d) 100 kW

11. For an SCR, the gate cathode characteristic has a straight line slope of 140. For trigger source voltage of 20 V and allowable gate power dissipation of 0.5 Watts, what is the gate source resistance?

- (a) 200 Ω (b) 255 Ω
(c) 195 Ω (d) 185 Ω

12. An AC capacitor is to be switched in parallel with AC line using back to back connected thyristor. What is the firing angle of thyristor for first switching?

- (a) 0° (b) 180°
(c) 90° (d) 45°

13. A communication channel is to receive signal power S and the noise at the receiver input is additive thermal noise, with uniform power spectral density (pad). It is found that if the bandwidth is 1 MHz the channel capacity is 10 Mbps. What would be the channel capacity for the same signal power and same noise psd, if the bandwidth is unlimited (tends to be infinite)?
(a) Zero (b) Infinite
(c) 15 Mbps (d) 1.5 Gbps

14. Match list I with list II and select the correct answer using the code given below the lists:

List I**(Microprocessor pin)**

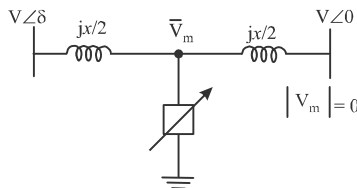
- A. TRAP
B. HLDA
C. RESET
D. ALE

List II**(Signals on pin)**

1. Interrupt
2. Initializing
3. Enable
4. Memory access

	A	B	C	D
(a)	1	2	4	3
(b)	3	2	4	1
(c)	1	4	2	3
(d)	3	4	2	1

15. Consider the following statements:
1. Only even harmonics are present in the output
2. Provides more output per device for a given amount of distortion.
3. Core saturation of transformer is avoided.
4. Power supply hum is absent in the output.
Which of the above statements is/are correct for push-pull amplifier?
(a) 1 only (b) 1 and 2 only
(c) 1, 2 and 3 (d) 2, 3 and 4
16. In a transmission line, the mid-point voltage is maintained to V by a compensating device as shown in the circuit below. What is the real power flow through the line?



- (a) $\frac{V^2}{X} \sin \frac{\delta}{2}$ (b) $\frac{2V^2}{X} \sin \delta$
(c) $\frac{V^2}{X} \sin \delta$ (d) $\frac{2V^2}{X} \sin \frac{\delta}{2}$

17. What is the rotor copper loss of a 3 phase 550 Volt, 50 Hz, 6 poles induction motor developing 4.1 kW at the shaft with mechanical loss of 750 W at 970 rpm?
(a) 175 W (b) 150 W
(c) 100 W (d) 250 W

18. In what form, the initial energy will be released for the 200 MeV per fission by a neutron in a slow thermal nuclear reactor?

- (a) Heat energy
(b) Electromagnetic radiation
(c) Kinetic energy of particles and electromagnetic radiation
(d) Kinetic and sound energy

19. In a certain self biased Si npn transistor the dc base voltage is 3.2 V then what is the dc emitter voltage? (Assume the transistor is in linear-active mode)

- (a) 0.7 V (b) 2.5 V
(c) 3.2 V (d) 3.9 V

20. What is the correct 8085 assembly language instruction that stores the contents of H and L register into the memory locations 1080 H and 1081 H respectively?

- (a) SPHL 1080 H (b) SHLD 1080 H
(c) STAX 1080 H (d) SPHL 1081 H

21. For which one of the following modulated signals, the original message, up to a scaling factor can be recovered using envelope detection?

- (a) $20 \cos(200\pi t) + 30 m(t) \cos(200\pi t)$
(b) $20 \cos(200\pi t) + 16 m(t) \cos(200\pi t)$
(c) $10 m(t) \cos(400\pi t)$
(d) $10 \cos m(t) \cos(400\pi t)$

22. An SCR is rated for 650 V PIV. What is the voltage for which the device can be operated if the voltage safety factor is 2?

- (a) 325 V rms (b) 230 V rms
(c) 459 V rms (d) 650 V rms

23. A-6-pulse SCR converter is connected to a 230 V, 3-phase, 50 Hz, AC mains and is controlling a DC drive with terminal voltage 205 volt and rated current of 105 Amp. The commutation angle $\mu = 18^\circ$ and firing angle $\alpha = 45^\circ$, what is the rating of shunt compensator and power factor?

- (a) 21.6 kVAR, 0.707 (b) 22.68 kVAR, 0.69
(c) 21.6 kVAR, 0.69 (d) 22.68 kVAR, 0.707

24. Which one of the following statements is correct?

The threshold effect in demodulators is

- (a) Exhibited by all receivers when the input SNR is low
(b) Exhibited only by correlation receivers
(c) The rapid fall in the output SNR when input SNR falls below a particular value
(d) The exponential rise in the output SNR when input SNR is increased above a particular value

25. The stack pointer of an 8085 microprocessor is ABCDH. At the end of execution of the sequence of instructions, what will be the content of the stack pointer?

PUSH PSW
XTHL
PUSH D
JMP FC70H

- (a) ABCB H (b) ABCHA H
(c) ABC9 H (d) ABC8 H

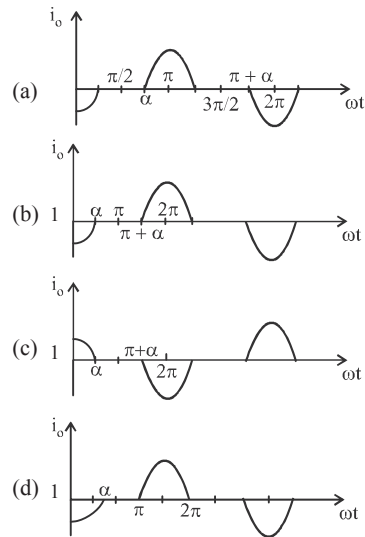
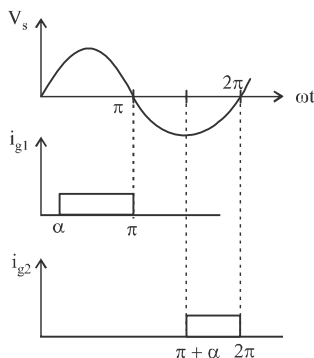
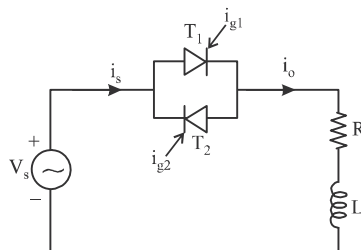
26. What is the main source of distortion in a push-pull amplifier?
 (a) Fundamental component
 (b) Second harmonic
 (c) Third harmonic
 (d) All even harmonics
27. Which one of the following is reduced by using stock bridge dampers on power overhead transmission lines?
 (a) Sag (b) Conductor vibration
 (c) Line losses (d) Mechanical tension
28. A single phase full converter feeds power to RLE load with $R = 10 \Omega$, $L = 10 \text{ mH}$ and $E = 50 \text{ V}$, the ac source voltage is 230 V , 50 Hz . For continuous conduction, what is the average value of load current for firing angle delay of 60° ?
 (a) 4.63 A (b) 6 A
 (c) 6.5 A (d) 5.35 A
29. An 8085 microprocessor is executing the programme as follows:

```

MVI A, 20 H
MVI B, 10 H
BACK: NOP
      ADD B
      JNC BACK
      HLT
    
```

How many times will the instruction NOP be executed?

- (a) 4 (b) 3
 (c) 2 (d) 1
30. In the AC regulator of figure-1, the supply voltage and gate currents waveforms are as in figure-2, what is the load voltage waveform for $R = 0$?



31. An amplifier without feedback, when fed with a 1 V , 50 Hz input signal gives an output of 30 V , 50 Hz with a 5% 2nd order distortion. When 10% of the output is feedback what is the 2nd order distortion?
 (a) 0.375 V (b) 1.3 V
 (c) 0.75 V (d) 3 V

32. Match list I with list II and select the correct answer using the code given below the lists:

List I

- A. Magnetic flux density
 B. Shunt admittance
 C. Attenuation co-efficient
 D. Phase-change co-efficient

List II

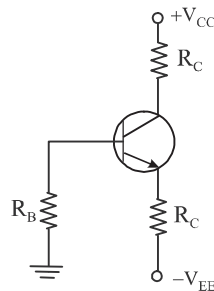
1. Siemens
 2. Tesla
 3. Radian
 4. Neper

Codes:

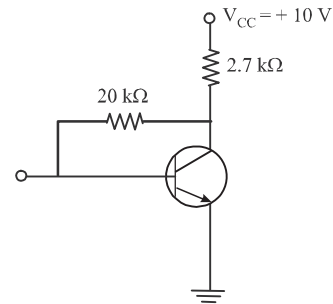
	A	B	C	D
(a)	3	4	1	2
(b)	2	4	1	3
(c)	3	1	4	2
(d)	2	1	4	3

33. What is the effect of the field failure of salient pole synchronous motor connected with infinite bus?
 (a) Reduce motor torque and speed
 (b) Not change motor torque and speed
 (c) Stop the motor
 (d) Reduce motor torque but motor will continue to run at synchronous speed
34. A DC chopper is used in regenerative braking mode of a dc series motor. The dc supply is 600 V , the duty cycle is 70% . The average value of armature current is 100 A . It is continuous and ripple free. What is the value of power feedbacks to the supply?
 (a) 3 kW (b) 9 kW
 (c) 18 kW (d) 35 kW
35. What is the ratio of starting torque and maximum torque of a 3 phase, 50 Hz , 4 pole induction motor for a maximum torque at 1200 rpm ?

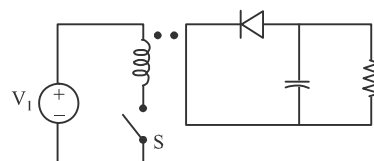
- (a) 0.421 (b) 0.384
(c) 0.6 (d) 0.5
36. When a transistor is used in switching mode then what is the turn-on time?
(a) Sum of delay time and rise time
(b) Sum of rise time and storage time
(c) Sum of delay rise time all fall time
(d) Sum of rise time and fall time
37. For which one of following, the instruction XRA. A in 8085 microprocessor can be used?
(a) Set the carry flag
(b) Set carry flag
(c) Reset the carry flag and clear the accumulator
(d) Transfer FFH to the accumulator
38. If a full wave fully controlled converter is modified as a full wave half controlled converter, what will be the maximum value of active power (p) and the maximum value of reactive power demand (Q)?
- | P | Q |
|---------------|-----------|
| (a) Double | Half |
| (b) Unchanged | Unchanged |
| (c) Half | Double |
| (d) Unchanged | Half |
39. The power input to a 415 V, 50 Hz, 6 pole 3-phase induction motor running at 975 rpm is 40 kW. The stator losses are 1 kW and friction and windage asses total 2 kW. What is the efficiency of motor?
(a) 92.5% (b) 92%
(c) 90% (d) 88%
40. A short transmission line having zero resistance and total series reactance of 0.4 pu is provided with reactive power compensation at the mid-point of the line such that the mid-point voltage is held at 0.96 pu when the voltage at both ends are 1.0 pu. What is the steady state power transmission limit of such a system?
(a) 4.8 pu (b) 0.0 pu
(c) 2.4 pu (d) 9.6 pu
41. In single pulse modulation of PWM inverters, the pulse width is 120°. For an input voltage of 220 V dc, what is the rms value at the fundamental component of the output voltage?
(a) 171.5 V (b) 254.0 V
(c) 127.0 V (d) 89.81 V
42. The Si transistor as shown in the circuit below has $\beta = 50$ and negligible leakage current. If $V_{CC} = 18$ V, $V_{EE} = 4$ V, $R_E = 200 \Omega$, $R_C = 4$ k Ω , $mR_B = 72$ k Ω , what is the value of the quiescent collector current I_{CQ} ? $\beta = 50$
(a) 1.1 mA
(b) 2 mA
(c) 5 mA
(d) 3.6 mA



43. An output device is interfaced with an 8085 microprocessor as memory-mapped I/O. The address of the device is 1000 H. In order to output data from the accumulator to the device, what will be the sequence of instructions?
(a) LXI H, 1000H
MOV A, M
(b) LXI H, 1000H
MOV M, A
(c) LHLD, 1000H
MOV A, M
(d) LHLD, 1000H
MOV M, A
44. What is the form of the Ybus matrix for carrying out load flow studies by Gauss-Seidal method of a power system having mesh connection of nodes?
(a) Symmetric but not diagonal matrix
(b) Diagonal matrix
(c) Antisymmetric matrix
(d) Sparse asymmetric matrix
45. In the below circuit as shown $\beta = 99$, $V_{BE} = 0.6$ V, then what are the values of V_C and I_C corresponding to the operating point?



- (a) 4.6 V and 1.98 mA (b) 4.7 V and 2.00 mA
(c) 5.4 V and 1.56 mA (d) 4.2 V and 2.1 mA
46. Two fully controlled three-phase bridges are connected in anti parallel across a load to provide reversible DC voltage to the load. The bridge operate in circulating current mode. The input is 3-phase 440 volt, 50 Hz. AC supply, and the maximum load current is 30 Amp. The peak value of the circulating current is taken to be 6 A. What is the value of inductance for limiting circulating current?
(a) 30 mH (b) 32 mH
(c) 36 mH (d) 38 mH
47. For the isolated buck boost converter as shown in the circuit below, the output is to 35 V at a duty cycle of 30%. The DC input is obtained from a front end rectifier without voltage doubling fed from a 115 V AC. What is the peak forward blocking voltage of the switching element?



- (a) 232.3 V (b) 69.69 V
(c) 162.61 V (d) 542 V

48. If the amplification of a single stage is not sufficient or the input or output impedance is not of the correct magnitude for the intended application how may two states be connected to achieve desired result?
(a) Cascode connection
(b) Complementary symmetry connection
(c) Cascade connection
(d) Totem pole connection

Directions: Each of the next eleven (11) items consists of two statements, one labelled as the 'Assertion (A)' and the other as 'Reason (R)' You are to examine these two statements carefully and select the answer to these items using the codes given below.

Codes:

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is not the correct explanation A
(c) A is true but R is false
(d) A is false but R is true
49. Assertion (A): The rotor speed of induction motor is less than the synchronous speed of rotating magnetic field.
Reason (R): At synchronous speed motor torque is zero.
50. Assertion (A): Rotor core loss at rated speed of induction motor is negligibility small.
Reason (R): Induced emf frequency of the rotor circuit at rated speed is very low, because slip of the motor at rated speed is low.
51. Assertion (A): A capacitor is connected in the polarizing circuit of the mho relay to prevent its in operation when three phase faults occur very close to the relay.
Reason (R): Capacitor provides memory action and thus maintains polarizing flux for several cycles following the fault.
52. Assertion (A): In small-signal R-C coupled amplifiers the gain falls in the high frequency range.
Reason (R): The decline in gain with frequency is due to the reactance of the coupling capacitor.
53. Assertion (A): In a typical RC coupled amplifier, the gain falls at high frequencies.
Reason (R): The amplifier has to use coupling capacitors in the input and output side for isolating dc biasing circuit and ac signal.
54. Assertion (A): The DAC (digital analog converter) cannot be interfaced to microprocessor in an interrupt driven mode.
Reason (R): DAC neither needs a start convert pulse nor it has indication of conversion.
55. Assertion (A): Monostable multivibrators (IC 74121) are used in a microprocessor based system for frequency measurement.
Reason (R): Microprocessor counts the number of interrupt signs/second or within a specified interval through ISR.

56. Assertion (A): Equalizers are used in receivers to increase the SNR of the demodulator.

Reason (R): The equalizer is designed such that, their transfer function is inversely related to that of the channel.

57. Assertion (A): FM is capable of exchanging SNR for the transmission bandwidth while in AM systems this feature is not available.

Reason (R): Transmission bandwidth in FM systems is much higher than in AM systems.

58. Assertion (A): DSB modulation scheme is superior to SSB modulation scheme as far as noise performance is concerned.

Reason (R): DSB modulation requires twice the bandwidth as compared to SSB modulation.

59. Assertion (A): FSK signalling is inferior to PSK signalling

Reason (R): PSK requires less bandwidth than FSK

60. Assertion (A): QPSK modulation allows higher data rate than BPSK for the same bandwidth occupying.

Reason (R): Gray code is used for the 4 signals transmitted in QPSK.

61. Consider the following tests:

1. Load test
2. Short circuit test
3. OC test
4. Retardation test

Which of the below test are to be conducted for the determination of voltage regulation of a transformer?

- (a) 1 only (b) 2 only
(c) 2 and 3 (d) 3 and 4

62. A three phase 50 Hz, 11 kV and 37.5 MW 0.9 p.f. capacity synchronous generator has its stator bore diameter of 765 cm and an axial core length of 80 cm. For which power plant this generator is suitable?

- (a) Thermal coal fired plant
(b) Hydroelectric power plant.
(c) Nuclear power plant
(d) Pumped storage power plant

63. A transistor has a maximum power dissipation limit of 300 mW for ambient temperature up to 25°C. If the maximum allowable junction temperature is 175°C, then what is the limit of the device in an ambient temperature of 55°C?

- (a) 120 mW (b) 240 mW
(c) 300 mW (d) 360 mW

64. Which stack is used in 8085 microprocessors?

- (a) FIFO (b) FILO
(c) LIFO (d) LILO

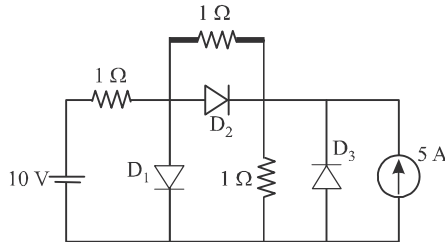
65. An angle modulated signal is described by the equation

$$x_c(t) = 10 \cos \left[-2\pi f_c t + 10 \sin(4000\pi t) + 5 \sin 2000\pi t \right]$$

What is the bandwidth of this modulated signal?

- (a) 6 kHz (b) 45 kHz
(c) 54 kHz (d) 63 kHz

66. If the turn on and turn off energy losses in a transmitter are 51 mJ and 76.8 mJ respectively and the mean power loss is limited to 200 W, what is the maximum switching rate that can be achieved?
(a) 15649 cycles/s (b) 156.49 cycles/s
(c) 1564.9 cycles/s (d) 15.649 cycles/s
67. The antenna current of AM transmitter is 8 A when only carrier is sent, but it increases to 8.93 A when the carrier is modulated. Then what is the percentage modulation of the wave?
(a) 43.00% (b) 70.14%
(c) 57.00%(d) (d) 100.00%
68. What are the states of the three ideal diodes in the circuit as shown below?



D_1	D_2	D_3
(a) On	Off	Off
(b) Off	On	Off
(c) On	Off	On
(d) Off	On	On

69. Number of thyristors, each with a rating of 500 V, 75 A required in each branch of a series-parallel combination for a circuit with a total voltage and current ratings of 7.5 kV and 1 kA respectively. If the device derating factor is 14 %, then what is the number of thyristors in series and parallel branch respectively?

No of thyristors in series branch	No of thyristors in parallel branch
(a) 18	16
(b) 15	14
(c) 15	12
(d) 16	18

70. Where is the draft tube of a hydropower station that is an air-tight pipe located?
(a) Near the surge tank
(b) In between the penstock and the runner
(c) In between the runner exhaust and the tailrace
(d) At the beginning of penstock
71. An F.M. signal which is modulated by a 4 kHz. sine wave reaches a maximum frequency of 100.01 MHz and minimum frequency of 99.97 MHz, then what is the one side frequency deviation of the signal?
(a) 6.67 (b) 5.00
(c) 10.0 (d) 20.0

72. What is the power transmitted inductively in an auto-transformer which supplies a load at 161 volts with an applied primary voltage of 230 volts?
(a) 35% of the input (b) 70% of the input
(c) 15% of the input (d) 30 % of the input

73. The starting current and torque of a three phase induction motor on direct line starting is 30 Amp and 300 Nm respectively. What are the corresponding values with star delta starter?
(a) 10 A and 100 Nm (b) 30 A and 300 Nm
(c) 17.32 A and 173.2 Nm (d) 30 A and 173.3 Nm

74. Consider the following statements:

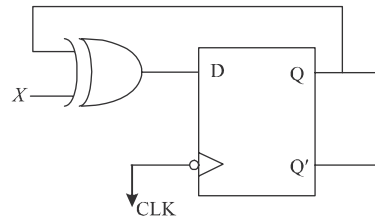
HVDC transmission is superior to HVAC transmission due to

1. Lack of reliable DC circuit breakers.
2. Lesser number of conductors for same power carrying capacity.
3. Non synchronous link between two different systems simplifying the problem of voltage stability and frequency control.
4. No costly terminal equipments such as converters and inverters are required

Which of the above statements is/are correct?

- (a) 4 only (b) 4 and 3
(c) 1 and 3 (d) 2 and 3

75. The digital circuit as shown below represents to which one of the following?



- (a) JK flip-flop (b) Clocked RS flip-flop
(c) T flip-flop (d) Ring counter

76. Consider the following:

1. Sign flag
2. Trap flag
3. Parity flag
4. Auxiliary carry flag

Which of the above flags is/are present in 8085 microprocessors?

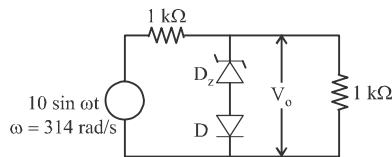
- (a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 1, 3 and 4

77. Which one of the following is not a part of typical TV receiver?

- (a) Sweep signal generator
(b) Envelope detector
(c) Video amplifier
(d) Pre-emphasis circuit

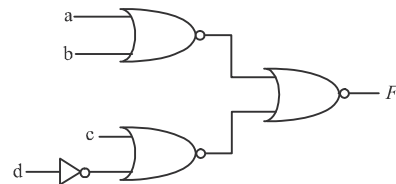
78. The anode current through a conducting SCR is 10 A. If its gate current is made one-fourth, then what will be the anode current?

- (a) 0 A (b) 5 A
(c) 10 A (d) 20 A
79. What is the power transferred conductively from primary to secondary of an auto-transformer having transformation ratio of 0.8 supplying a load of 3 kW?
(a) 0.6 kW (b) 2.4 kW
(c) 1.5 kW (d) 0.27 kW
80. Consider the following statements concerning steam power plants:
1. Maintenance and operating costs are low.
2. Water is required in huge quantity.
3. Requires long time for installation.
4. Handling of coal and disposal of ash can be done easily.
Which of the above statements is/are correct?
(a) 1 only (b) 2 and 3
(c) 3 only (d) 3 and 4
81. The cut-in voltage of zener diode D_z and diode D shown in the figure below is 0.7 V. Breakdown voltage of D_z is 3.3 V and reverse breakdown voltage of D is 50 V. The other parameters can be assumed to be the same as those of an ideal diode. Then what are the values of the peak output voltage V_o ?

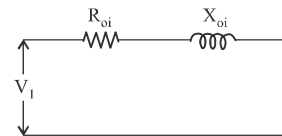


Positive Half cycle in V	Negative Half cycle in V
(a) 3.3	1.4
(b) 4	5
(c) 3.3	3.3
(d) 4	4
82. Consider the following statements:
In 8085 microprocessor, data-bus and address-bus are multiplexed in order to
1. Increase the speed of microprocessor
2. Reduce the number of pins
3. Connect more peripheral chips.
Which of the above statements is/are correct?
(a) 1 only (b) 2 only
(c) 2 and 3 (d) 1, 2 and 3
83. In a power circuit of 3 kV, four thyristor each of rating 800 V are connected in series. What is the percentage series derating factor?
(a) 50 (b) 25
(c) 12.5 (d) 6.25
84. What is the core loss in a high frequency ferrite core transformer used in SMPS power supply?
(a) 10% of rated power
(b) 5 % of rated power
(c) 2% of rated power
(d) 1 % of rated power

85. Which one of the following is considered as an A.M. signal?
(a) Binary phase shift keying (BPSK)
(b) Differential phase shift keying (DPSK)
(c) Differential encoded PSK
(d) Quadrature PSK
86. For 16 bit address-bus, if an 8 K RAM chip is selected when, A13, A14 and A15 address bits are all one, then what is the range of the memory address?
(a) E000H - EFFFH (b) E000H - FFFFH
(c) F000H - FFFFH (d) F000H - FEEEH
87. Which one of the following is the correct output (f) of the below circuit?



- (a) $(a + b)(c + \bar{d})$ (b) $(\bar{a} + \bar{b})(c + \bar{d})$
(c) $(a + \bar{b})(c + \bar{d})$ (d) $(a + b)(\bar{a} + \bar{d})$
88. The making and breaking currents of 3 phase ac circuit breakers in power system are respectively in what form?
(a) r.m.s. value, r.m.s. value
(b) instantaneous value, r.m.s. value
(c) r.m.s value
(d) instantaneous value, instantaneous value
89. A three phase 6 pole 50 Hz induction motor is running at 50% slip. What is the speed of the motor?
(a) 850 rpm (b) 900 rpm
(c) 950 rpm (d) 1000 rpm
90. At which condition of the transformer the equivalent circuit will be as shown in the below figure?



- (a) Under short circuit (b) Under open circuit
(c) Under no load (d) Under rated load
91. What is the nominal pH value of water that is to be maintained in a steam raising thermal power station?
(a) 0-0 (b) 7-0
(c) 8.5 (d) 14.3
92. Consider the following statements about a Tunnel diode:
1. Tunnelling takes place at a speed decided by junction temperature.
2. Concentration of impurities is of the order 1 part in 10^3 .
3. Both tunnelling current and normal pn junction injection current exist.
4. Tunnel diode exhibits current controlled negative resistance, characteristic, only.

Which of the above statements is/are correct?

- (a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 3 and 4

93. In an instruction of 8085 microprocessor, how many bytes are present?

- (a) One or two (b) One, two or three
(c) One only (d) Two or three

94. Which one of the following factors is limited in case of F.M.?

- (a) Maximum frequency deviation
(b) Maximum permissible modulation index
(c) Signal to noise voltage ratio
(d) Minimum permissible modulation index.

95. Consider the following statements, with respect to the power transistors used in inverters?

1. Maximum collector-emitter voltage V_{CE} .
2. Maximum collector current.
3. Maximum power dissipation.
4. Maximum current gain at minimum load current.
5. Maximum current gain at maximum load current.

Which of the above statements is/are correct?

- (a) 1 only (b) 1, 2, 3 and 5
(c) 2 and 3 only (d) 2, 3 and 4

96. When will a slip ring induction motor run at super synchronous speed?

- (a) If a voltage is injected in the rotor circuit in phase opposition to the rotor induced emf
(b) If an emf is injected in the rotor circuit in phase with the rotor induced emf
(c) If motor is coupled with active load
(d) If motor is coupled with passive load

97. Consider the following statements:

1. Present day surge diverters use non-linear resistance elements.

2. A travelling wave is usually represented as a step wave in the analysis.

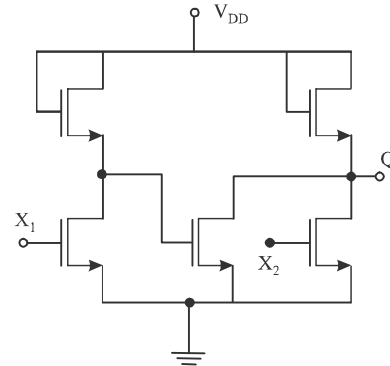
3. A travelling wave suffer reflection when it reaches a discontinuity

4. The function $(f(vx - t))$ represents a travelling wave.

Which of the above statements is/are correct?

- (a) 1 only (b) 1 and 2 only
(c) 1, 2 and 3 (d) 3 and 4 only

98. If X_1 and X_2 are the inputs to the circuit as shown in the below figure, then what is the output Q ?



- (a) $(X_1 + X_2)'$ (b) $(X_1 - X_2)'$
(c) $(X_1 \cdot X_2)$ (d) $(X_1 \cdot X_2)'$

99. To address the memory 14 bits are used. Then what is the address of the last memory location?

- (a) 16382 (b) 16383
(c) 16384 (d) 16385

100. Which one of the following modulation technique is most affected by noise?

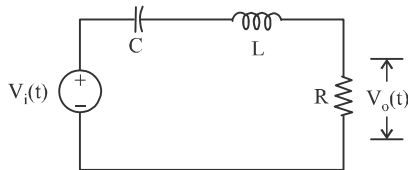
- (a) ASK (b) PSK
(c) FSK (d) MSK

ANSWER KEYS

1. (d)	2. (b)	3. (c)	4. (d)	5. (b)	6. (b)	7. (c)	8. (b)	9. (c)	10. (c)
11. (c)	12. (c)	13. (b)	14. (c)	15. (d)	16. (c)	17. (b)	18. (c)	19. (b)	20. (a)
21. (b)	22. (b)	23. (d)	24. (c)	25. (c)	26. (c)	27. (b)	28. (d)	29. (b)	30. (a)
31. (a)	32. (d)	33. (d)	34. (c)	35. (b)	36. (a)	37. (b)	38. (b)	39. (c)	40. (c)
41. (a)	42. (b)	43. (b)	44. (a)	45. (a)	46. (a)	47. (c)	48. (c)	49. (a)	50. (a)
51. (a)	52. (a)	53. (b)	54. (a)	55. (a)	56. (d)	57. (a)	58. (a)	59. (b)	60. (a)
61. (c)	62. (b)	63. (b)	64. (c)	65. (b)	66. (d)	67. (b)	68. (a)	69. (a)	70. (b)
71. (b)	72. (d)	73. (a)	74. (d)	75. (c)	76. (b)	77. (b)	78. (c)	79. (b)	80. (b)
81. (d)	82. (b)	83. (c)	84. (d)	85. (d)	86. (b)	87. (a)	88. (d)	89. (c)	90. (a)
91. (c)	92. (c)	93. (b)	94. (a)	95. (b)	96. (a)	97. (c)	98. (d)	99. (b)	100. (a)

TEST PAPER 3

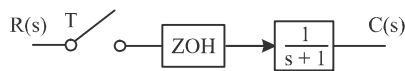
1. For the below network, the function $G(s) = \frac{V_o(s)}{V_i(s)}$ is $\frac{4s}{s^2 + 4s + 20}$ when R is 2 ohm. What is the value of L and C?



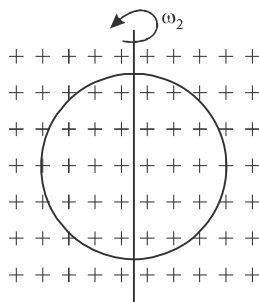
- (a) 0.3 H and 1 F (b) 0.4 H and 0.5 F
(c) 0.5 H and 0.1 F (d) 0.5 H and 0.01 F
2. The system matrix of a linear time invariant continuous time system is given by

$$A = \begin{bmatrix} -0 & 1 \\ 3 & -5 \end{bmatrix}. \text{ What is the characteristic equation?}$$

- (a) $s^2 + 5s + 3 = 0$ (b) $s^2 - 3s - 5 = 0$
(c) $s^2 + 3s + 5 = 0$ (d) $s^2 + s + 2 = 0$
3. What is the transfer function $\frac{C(Z)}{R(Z)}$ of the sampled data system as shown below?

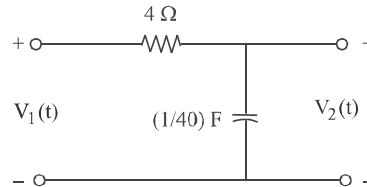


- (a) $\frac{(1 - e^{-T})}{(Z - e^{-T})}$ (b) $\frac{(Z - e^{-T})}{(1 - e^{-T})}$
(c) $\frac{(1 - 2e^{-T})}{(e^{-T} - Z)}$ (d) $\frac{(1 - 2Ze^{-T})}{(Z - 1)}$
4. A circular loop placed perpendicular to a uniform sinusoidal magnetic field of frequency ω_1 is revolved about an axis through its diameter at an angular velocity ω_2 rad/sec ($\omega_2 < \omega_1$) as shown in the figure below. What are the frequencies for the e.m.f. induced in the loop?



- (a) ω_1 and ω_2
(b) $\omega_1, \omega_2 + \omega_2$ and ω_2
(c) $\omega_2, \omega_1 - \omega_2$ and ω_2
(d) $\omega_1 - \omega_2$ and $\omega_1 + \omega_2$

5. Consider the following with respect to the below circuit:

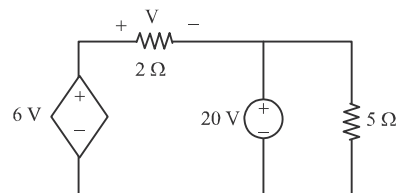


1. The transfer function of the circuit is $\frac{10}{s+10}$
2. If $V_1(t) = 20$, $V_2(t) = 20(1 - e^{-10t})$
3. If $V_1(t) = 20\sin 10t$,

$$V_2(s) = \frac{2000}{(s+10)(s^2+100)}$$

Which of these is/are correct?

- (a) 1 only (b) 1 and 2
(c) 1, 2 and 3 (d) 2 only
6. What is the initial slope of Bode magnitude plot of a type-2 system?
(a) -20 db/decade (b) +20 db/decade
(c) -20db/decade (d) +40 db/decade
7. In free space
 $\vec{E}(Z, t) = 120 \pi \cos(\omega t - \beta Z) \vec{a}_x \text{ Vm}^{-1}$
What is the average power is Wm^{-2} ?
(a) $30\pi \vec{a}_z$ (b) $60\pi \vec{a}_z$
(c) $90\pi \vec{a}_z$ (d) $120\pi \vec{a}_z$
8. What is the current through the 2Ω resistance for the circuit as shown below?



- (a) 5 A (b) 4 A
(c) 3 A (d) 2 A
9. The open-loop transfer function of a system has one pole in the right of s-plane. If the system is to be closed loop stable, then $(-1 + j0)$ point should have how many encirclements in the GH-plane?

- (a) -1 (b) -1
(c) $+1$ (d) $+2$

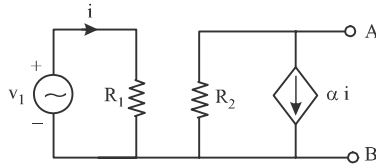
10. Consider the following statements in connection with cylindrical waveguides:

1. At low frequency the propagation constant is real and wave does not propagate.
2. At intermediate frequency the propagation constant is zero and wave cuts off.
3. At high frequency the propagation constant is imaginary and wave propagates.
4. At transition condition the cut-off frequency is inversely proportional to the eigen values of the Bessel function for the respective TE_{nm} mode.

Which of the above statements is/are correct?

- (a) 1, 2 and 3 (b) 2 only
(c) 2 and 3 only (d) 2, 3 and 4

11. For the circuit as shown below, what are the values of the Norton's equivalent current and conductance between AB terminals?

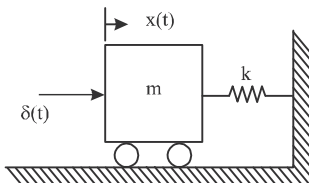


- (a) $-\alpha \frac{v_1}{R_1}$ and $G = \frac{1}{R_2}$
(b) $\alpha \frac{v_1}{R_1}$ and $G = \frac{1}{R_2}$
(c) $-\frac{v_1}{R_1}$ and $G = \frac{1}{R_2}$
(d) $-\alpha \frac{v_1}{R_1}$ and $G = -\frac{1}{R_2}$

12. A 100 kV, 50 Hz supply is fed to a rectifier ammeter (using a bridge rectifier) through a capacitor. The PMMC ammeter of the rectifier instrument reads 45×10^{-3} Amps. What is the value of the capacitor?

- (a) $15.90 \times 10^{-10} F$ (b) $15.90 \times 10^{-12} F$
(c) $17.66 \times 10^{-9} F$ (d) $17.66 \times 10^{-11} F$

13. A mechanical system is as shown in the figure below. The system is set into motion by applying unit impulse force $\delta(t)$. Assuming that the system is initially at rest and ignoring friction, what is the displacement $x(t)$ of mass?



- (a) $\frac{1}{\sqrt{k}} e^{(-m t)}$ (b) $\frac{1}{\sqrt{mk}} \sin(t)$
(c) $\frac{1}{\sqrt{mk}} \sin \sqrt{\frac{k}{m}} t$ (d) $\frac{1}{\sqrt{mk}} \sqrt{\frac{k}{m}} t$

14. For the circuit as shown in figure (a), the current through the ammeter is $4 \angle -45^\circ$ Amps. What is the current in the ammeter for the circuit in figure (b)?

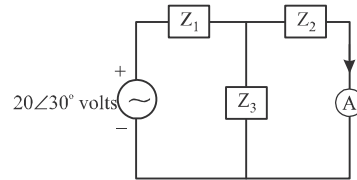


Figure (a)

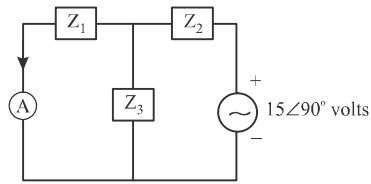


Figure (b)

- (a) $4 \angle 15^\circ$ Amps (b) $2 \angle 30^\circ$ Amps
(c) $4 \angle 45^\circ$ Amps (d) $5 \angle -90^\circ$ Amps

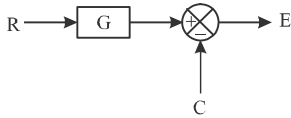
15. The electric field of a uniform plane wave is given by

$$\vec{E} = 10 \sin(3\pi \cdot 10^8 t - \pi Z) \vec{a}_x + 10 \cos(3\pi \cdot 10^8 t - \pi Z) \vec{a}_y \text{ Vm}^{-1}.$$

What is the corresponding magnetic field $\vec{H}$?

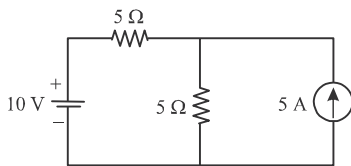
- (a) $\frac{10}{377} \sin(3\pi \cdot 10^8 t - \pi Z) \vec{a}_y + \frac{10}{377} \cos(3\pi \cdot 10^8 t - \pi Z) (-\vec{a}_x) \text{ Am}^{-1}$
(b) $\frac{10}{377} \sin(3\pi \cdot 10^8 t - \pi Z) (-\vec{a}_y) + \frac{10}{377} \cos(3\pi \cdot 10^8 t - \pi Z) (-\vec{a}_x) \text{ Am}^{-1}$
(c) $\frac{10}{377} \sin(3\pi \cdot 10^8 t - \pi Z) \vec{a}_y + \frac{10}{377} \cos(3\pi \cdot 10^8 t - \pi Z) (\vec{a}_x) \text{ Am}^{-1}$
(d) $\frac{10}{377} \sin(3\pi \cdot 10^8 t - \pi Z) (-\vec{a}_y) + \frac{10}{377} \cos(3\pi \cdot 10^8 t - \pi Z) (\vec{a}_x) \text{ Am}^{-1}$

16. Which one of the following block diagrams is equivalent to the below shown block diagram?



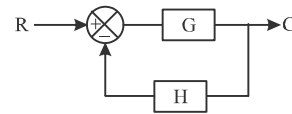
- (a)
- (b)
- (c)
- (d)

17. What is the voltage across the current source for the below shown circuit?



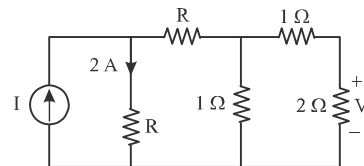
- (a) 5.0 V (b) 7.5 V
(c) 12.5 V (d) 17.5 V
18. Consider the following statements:
In the Hall effect experiment, the sign of Hall voltage will change if
1. Direction of applied field is changed
 2. Direction of applied magnetic field is changed
 3. Direction of both applied electric and magnetic field is changed
 4. Direction of current is changed.
- Which of the above statements is/are correct?
- (a) 1, 2 and 3 (b) 3 only
(c) 1, 2 and 4 (d) 3 and 4
19. Consider the following statements in connection with electromagnetic waves:
1. Conducting medium behaves like an open circuit to the electromagnetic field.
 2. At radio and microwave frequencies the relaxation time is much less than the period.
 3. In loss-less dielectric the relaxation time is infinite.
 4. Intrinsic impedance of perfect dielectric medium is a pure resistance.
- Which of the above statements is/are correct?
- (a) 1 only (b) 1 and 2 only
(c) 2 and 3 only (d) 2, 3 and 4

20. The below shown feedback control system has to be reduced to equivalent unity feedback system. Which one of the following is equivalent?



- (a)
- (b)
- (c)
- (d)

21. What is the value of I for the below shown circuit, if $V = 2$ volts?



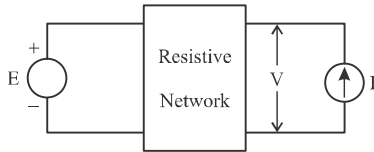
- (a) 2 A (b) 4 A
(c) 6 A (d) 8 A
22. In semiconductor strain gauges, what happens when a tensile strain is applied?
- (a) Resistance increases in N-type of materials
(b) Resistance increase in P-type of materials
(c) Resistance increases in both P and N-type of materials
(d) Resistance decreases in both P and N-type of materials
23. For intrinsic GaAs, the room-temperature electrical conductivity is $10^{-6} (\text{ohm-m})^{-1}$, the electron and hole mobilities are, respectively, 0.85 and $0.04 \text{ m}^2/\text{V-s}$. What is the intrinsic carrier concentration n_i at the room temperature?
- (a) 10^{-21} m^{-3} (b) 10^{-20} m^{-3}
(c) $7.0 \times 10^{+20} \text{ m}^{-3}$ (d) $7.0 \times 10^{-20} \text{ m}^{-3}$
24. A second order system has a natural frequency of oscillation of 3 rad/sec and damping ratio of 0.5. What are the values of resonant frequency and resonant peak of the system?
- (a) 1.5 rad/sec and 1.16 (b) 1.16 rad/sec and 1.5
(c) 1.16 rad/sec and 2.1 (d) 2.1 rad/sec and 1.16
25. A transmission line of characteristic impedance of 50 ohm is terminated by a load impedance of $(15 - j20) \text{ ohm}$. What is the normalized load impedance?

- (a) $0.6 - j0.8$ (b) $0.3 - j0.6$
 (c) $0.3 - j0.4$ (d) $0.3 + j0.4$

26. The response of an initially relaxed, linear constant-parameter network to a unit impulse applied at $t = 0$ is $4e^{-2t}u(t)$. What is the response of this network to unit step function?

- (a) $2(1 - e^{-2t})u(t)$ (b) $4(e^{-2t} - e^{-4t})u(t)$
 (c) $\sin 2t$ (d) $(1 - 4e^{-4t})u(t)$

27. In the below shown circuit, if $V = 3$ volts for $E = 1$ Volt, $E = 1$ volts, $I = 0$, and $V = 2$ volts for $I = 2$ A and $E = 0$. When $E = 1$ volt and I is replaced by a resistor of 2 ohm , then what is the value of V ?



- (a) 2 volts (b) 4 volts
 (c) 6 volts (d) 8 volts

28. For a certain thermistor, the material constant (β) is 3000 kelvin and its resistance at 27°C is 1050 ohm . What is the temperature coefficient of resistance for this thermistor?

- (a) $0.033 \times 10^{-3} \text{ ohm/ohm/}^\circ\text{C}$
 (b) $-0.033 \text{ ohm/ohm/}^\circ\text{C}$
 (c) $-3.33 \text{ ohm/ohm/}^\circ\text{C}$
 (d) $-3.0 \text{ ohm/ohm/}^\circ\text{C}$

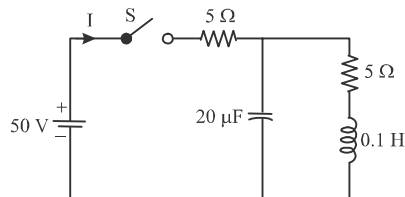
29. Consider the following statement:

1. A system is said to be stable if its output is bounded for any input.
2. A system is stable if all the roots of the characteristic equation lie in the left half of the s -plane.
3. A system is stable if all the roots of the characteristic equation have negative real parts.
4. A second order system is always stable for finite positive values of open loop gain.

Which of the above statements is/are correct?

- (a) 2, 3 and 4 (b) 1 only
 (c) 2 and 3 only (d) 3 and 4 only

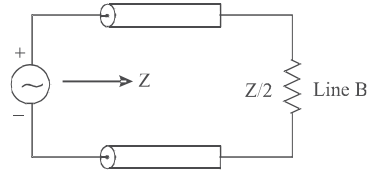
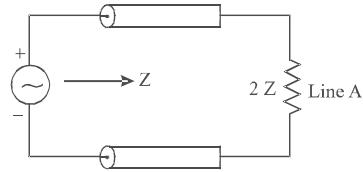
30. The network shown below is initially at rest. What is the initial current I when the switch S is closed at $t = 0$?



- (a) 0 A (b) 5 A
 (c) 10 A (d) 20 A

31. Two loss-less resistive transmission lines each of characteristic impedance Z are connected as shown in the circuit below. If the

maximum voltage on the two lines is the same and the power transmitted by line A is W_1 , then what is the power transmitted by the line B?



- (a) $4 W_1$ (b) $3 W_1$
 (c) $2 W_1$ (d) $1 W_1$

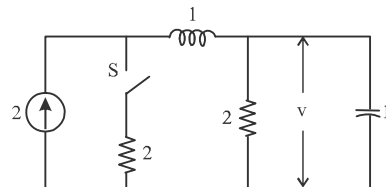
32. The open-loop transfer function of a closed loop control system is given as

$$G(s)H(s) = \frac{K(s+2)}{s(s+1)(s+4)^2}$$

What are the number of asymptotes and the centroid of the asymptotes of the root-loci of closed loop system?

- (a) $-3; \frac{7}{3}, 0$ (b) $-2; (2, 0)$
 (c) $3; \frac{-7}{3}, 0$ (d) $2; (2, 0)$

33. The circuit as shown below is in the steady state. The switch S is closed at $t = 0$. What are the value of v and $\frac{dv}{dt}$ at $t = 0^+$?



- (a) 0 and 4 (b) 4 and 0
 (c) 2 and 0 (d) 0 and 2

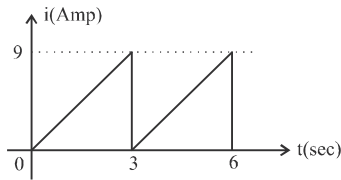
34. The transfer function of a phase-lead compensator is given by:

$$G(s) = \frac{1 + 3Ts}{1 + Ts}$$

Where $T > 0$. What is the maximum shift provided by such a compensator?

- (a) 90° (b) 60°
 (c) 45° (d) 30°

35. The current waveform as shown below, is applied in a pure resistor of 10 ohm . What is the power dissipated in the resistor?



- (a) 270 W (b) 135 W
(c) 52 W (d) 7 W

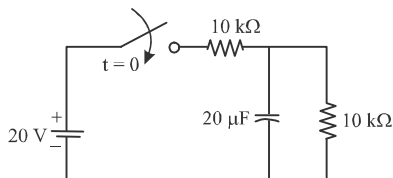
36. Consider the following statements:

1. A phase lead network provides a positive phase angle over the frequency range of interest.
2. Armature controlled dc servo motor is inherently a closed-loop system.
3. Phase lag network provides significant amplification over the frequency range of interest.
4. Transfer function with zeros in the right half of s-plane is a non-minimum system.

Which of the above statements is/are correct?

- (a) 3 only (b) 1 and 2 only
(c) 1, 2 and 4 (d) 2, 3 and 4

37. The switch of below circuit was open for long, and at $t = 0$ it is closed. What is the final steady state voltage across the capacitor and the time-constant of the circuit?



- (a) 0 V and 0.1 sec (b) 20 V and 0.2 sec
(c) 10 V and 0.2 sec (d) 10 V and 0.1 sec

38. A linear system is described by the following state equations:

$$\dot{X}(t) = \begin{bmatrix} -0 & -2 \\ 1 & -3 \end{bmatrix} X + \begin{bmatrix} -2 \\ 0 \end{bmatrix} Y$$

$$Y(t) = [0 \quad 3] X$$

What is the transfer function of the system?

- (a) $\frac{1}{s^2 + 2s + 3}$ (b) $\frac{6}{s^2 + 3s + 2}$
(c) $\frac{6}{s^2 + 2s + 3}$ (d) $\frac{1}{s^2 + 3s + 2}$

39. A transmission line section shows an input impedance of 36Ω and 64Ω respectively, when short circuited and open circuited. What is the characteristic impedance of the transmission line?

- (a) 100Ω (b) 50Ω
(c) 45Ω (d) 48Ω

40. The poles and zeroes of an all-pass network are located in which part of the s-plane?

- (a) Poles and zeroes are in the right half of s-plane
(b) Poles and zeroes are in the left half of s-plane

- (c) Poles in the right half and zeroes in the left half of s-plane
(d) Poles in the left half and zeroes in the right half of s-plane.

41. When a transfer function model is converted into state space model, the order of the system may be reduced during which one of the following conditions?

- (a) Some of the variables are not considered
(b) Some of the variables are hidden
(c) Pole, zero cancellation takes place
(d) The order of the system will never get changed

42. How can the power supplied to a high frequency heating system be measured?

- (a) By dynamometer wattmeter
(b) By induction wattmeter
(c) By thermocouple type wattmeter
(d) By moving iron ammeter and voltmeter

43. In an RLC series resonant circuit, if the maximum stored energy is increased by 10% and at the same time the energy dissipated per cycle is reduced by 10%, it will result in which one of the following?

- (a) An 11% decrease in quality factor
(b) An increase in the resonant frequency by 11%
(c) A 22% increase in quality factor
(d) A decrease in the resonant frequency by 22%

44. If D is the rotor diameter and L , the axial length, then a high performance ac servomotor is characterized by which one of the following?

- (a) Large D and Large L (b) Large D and Small L
(c) Small D and Small L (d) Small D and Large L

45. Why is the network function,

$$N(s) = \frac{s^3 + 3s}{s^4 + 4s^2 + 4} \text{ not positive real?}$$

- (a) The highest degree of numerator and denominator polynomials differ by one
(b) The terms of the lowest degree in the numerator and denominator polynomials differ in degree by one
(c) The poles and zeroes have zero real parts
(d) It has multiple poles on the imaginary axis

46. Consider the following statements with reference to hydraulic systems:

1. A small size actuator can develop a very large force or torque.
2. A source with supply and return line is required
3. It is insensitive to temperature changes

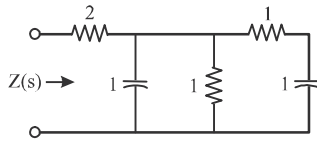
Which of the below statements is/are correct?

- (a) 1 only (b) 2 only
(c) 1 and 2 (d) 2 and 3

47. The network realization of RC impedance function

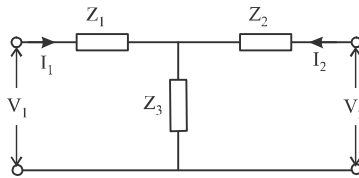
$$Z(s) = \frac{(\alpha s^2 + 7s + 3)}{(s^2 + 3s + \beta)}$$

is as shown below. What are the values of α and β ?



- (a) 1 and 2 (b) 2 and 1
(c) 2 and 3 (d) 3 and 2

48. Which one of the following is not the criterion used to select potentiometer in a control system?
(a) Accuracy (b) Noise
(c) Time response (d) Frequency response
49. If the Z-parameters for the T-network as shown below are $Z_{11} = 40 \Omega$, $Z_{22} = 50 \Omega$ and $Z_{12} = Z_{21} = 30 \Omega$, then what are the values of Z_1 , Z_2 and Z_3 ?



- (a) 10 Ω , 20 Ω and 30 Ω (b) 20 Ω , 30 Ω and 20 Ω
(c) 30 Ω , 40 Ω and 10 Ω (d) 40 Ω , 50 Ω and 10 Ω

Directions: Each of the next eleven (11) items consists of two statements, one labelled as the 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answer to these items using the codes given below

Codes:

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is not the correct explanation A
(c) A is true but R is false
(d) A is false but R is true

50. Assertion (A): The semiconductor material used in making an optical source should be a direct bandgap material.

Reason (R): Carrier recombination time is shorter in a direct bandgap semiconductor.

51. Assertion (A): A capacitance has one pole at $s = \infty$ and one zero at $s = 0$ where $s = j\omega$, ω is the angular frequency.

Reason (R): The driving point impedance of a capacitor is $(1/sC)$

52. Assertion (A): To increase the range of an ammeter to measure high currents, it is required to connect a high resistor in shunt across the ammeter.

Reason (R): The shunt resistor will divert the excess current and allow only the rated current to pass through the deflecting system of the ammeter.

53. Assertion (A): The sensitivity of a voltmeter is often expressed in terms of ohms per volt.

Reason (R): High sensitivity voltmeters use a basic d'Arsonval meter which has high sensitivity.

54. Assertion (A): In a bridge type of measurement, it is required that the indicator used to show the balance condition of the bridge should have very high sensitivity.

Reason (R): The accuracy of the null-indicator does not play any role in a bridge measurement.

55. Assertion (A): An electronic millivoltmeter used to read very low a.c. voltages at high frequencies is an amplifier-rectifier type of meter.

Reason (R): The diodes cannot rectify low a.c. voltages of millivolt order.

56. Assertion (A): Electron beam switch is used in a multitrace CRO

Reason (R): Electron beam switch synchronizes the input signal and gives a steady waveform on the CRO screen.

57. Assertion (A): Random errors can be minimized by statistical methods.

Reason (R): These are caused by arithmetic error while taking readings.

58. Assertion (A): The stator windings of a control transformer has higher impedance per phase.

Reason (R): The rotor of a control transformer is cylindrical in shape.

59. Assertion (A): Addition of a pole to the forward path transfer function of unity feedback system increases the rise time of step response.

Reason (R): The additional pole has the effect of increasing the bandwidth of the system.

60. Assertion (A): Knowing magnetic vector potential $\vec{A}$ at a point, the flux density $\vec{B}$ at that point can be obtained.

Reason (R):

$$\nabla \times \vec{A} = 0$$

61. What does the expression $\frac{1}{2} \vec{J} \cdot \vec{A}$ represent?

- (a) Power density
(b) Radiation resistance
(c) Magnetic energy density
(d) Electric energy density

62. Consider the following statements:

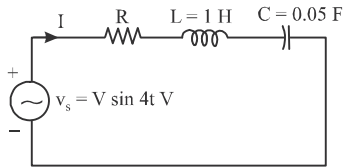
In an n-type semiconductor

1. Fermi level lies below the donor level at room temperature (T).
2. Fermi level lies above the donor level as $T \rightarrow 0$.
3. Fermi level lies in valence band
4. Fermi level remains invariant with temperature.

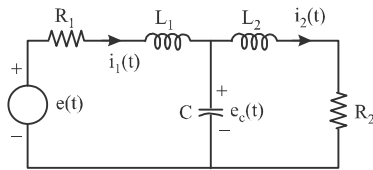
Which of the above statements is/are correct?

- (a) 1 only (b) 1 and 2 only
(c) 2, 3 and 4 (d) 1, 2 and 3

63. For the circuit as shown below, if the current leads the applied voltage by $\tan^{-1} 2$, what is the resistance value in ohm?



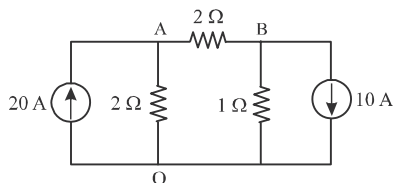
- (a) 0.5 (b) 1.0
(c) 2.0 (d) 9.5
64. The dead zone in a pyrometer is 0.125 percent of the span. The instrument is calibrated from 500°C to 200°C . What temperature change must occur before it can be detected in degree Centigrade?
- (a) 187.5 (b) 1.875
(c) 18.75 (d) 0.1875
65. Consider the following equations with respect to the below network:



1. $L_1 \frac{di_1(t)}{dt} = R_1 i_1(t) - e_c(t) + e(t)$
2. $L_1 \frac{di_1(t)}{dt} = -R_1 i_1(t) - e_c(t) + e(t)$
3. $L_2 \frac{di_2(t)}{dt} = -R_2 i_2(t) + e_c(t)$
4. $C \frac{de_c(t)}{dt} = i_2(t) - i_1(t)$

Which of the above statements is/are correct?

- (a) 1 only (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2 and 4
66. Find the voltage of the node A with respect to 'O' for the circuit as shown.



- (a) 40 V (b) 20 V
(c) 50 V (d) 60 V
67. Match list I with list II and select the correct answer using the code given below the lists:

List I
(Type of instrument)

- A. Indicating
B. Absolute
C. Recording
D. Integrating

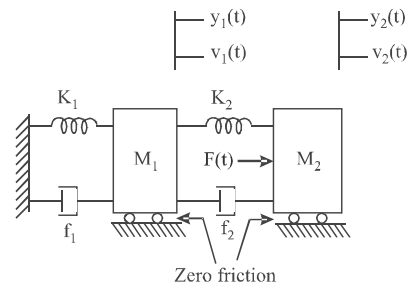
List II
(Example)

1. Wattmeter
2. Tangent galvanometer
3. Aneroid barometer
4. Energy meter

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	4	2	3	1
(c)	1	3	2	4
(d)	4	3	2	1

68. $y_1(t)$ and $y_2(t)$ are displacement $v_1(t)$ and $v_2(t)$ are velocities. Which one of the following is the correct free body diagram for the physical system as shown the figure below?



- (a)
- (b)
- (c)
- (d)

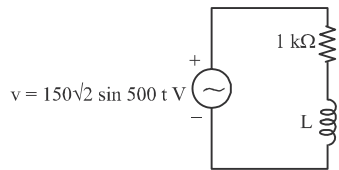
69. In a fluid flow system, two fluids are mixed in appropriate proportion. The concentration at the mixing point is $y(t)$ and it is reproduced without change, T_d seconds later at the monitoring point as $b(t)$. What is the transfer function between $b(t)$ and $y(t)$? (Where S is distance) between monitoring point and mixing point

- (a) $e^{-T_d S}$ (b) $e^{+T_d S}$
(c) $e^{-T_d S}$ (d) $e^{+T_d S}$

70. The strain gauge with a resistance of 250 ohm undergoes a change of 0.15 ohm. During a test the strain is 1.5×10^{-4} . What is the gauge factor?

(a) 4.7 (b) 4.0
(c) 3.5 (d) 2.0

71. For the AC circuit as shown below, if the rms voltage across the resistor is 120 V, what is the value of the inductor?

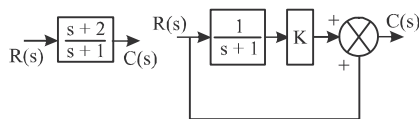


(a) 0.5 H (b) 0.6 H
(c) 1.0 H (d) 1.5 H

72. Which one of the following bridges will be used for the measurement of very low resistance?

(a) Kelvin bridge
(b) Maxwell's bridge
(c) Wheatstone bridge
(d) Hay's bridge

73. For what value of K, are the two block diagram as shown below equivalent?



(a) 1 (b) 2
(c) (s + 1) (d) (s + 2)

74. Consider the following:

1. Rise time
2. Settling time
3. Delay time
4. Peak time

What is the correct sequence of the time domain specifications of a second order system in the ascending order of the values?

(a) 2 - 4 - 1 - 3 (b) 3 - 4 - 1 - 2
(c) 2 - 1 - 4 - 3 (d) 3 - 1 - 4 - 2

75. The oscilloscope has an input capacitance of 50 pF and a resistance of 2M Ω and the voltage divider ratio (k) of 10. What are the parameters of a high-impedance probe?

(a) $C_1 = 5.55 \text{ pF}$ and $R_1 = 9 \text{ M}\Omega$
(b) $C_1 = 5.55 \text{ pF}$ and $R_1 = 18 \text{ M}\Omega$
(c) $C_1 = 3.33 \text{ pF}$ and $R_1 = 18 \text{ M}\Omega$
(d) $C_1 = 1.11 \text{ pF}$ and $R_1 = 18 \text{ M}\Omega$

76. A unity feedback system with open loop transfer function of $\frac{20}{s(s+5)}$ is excited by a unit step input. How much time will be required for the response to settle within 2% of final desired values?

(a) 0.25 sec (b) 1.60 sec
(c) 2.40 sec (d) 4.00 sec

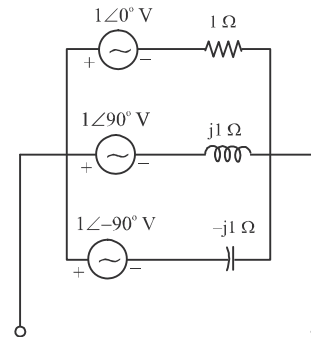
77. Consider the following statements:

1. Amplifier gain and phase shift.
2. Filter transfer functions.
3. Two port network parameter.
4. Power gain in a two port circuit

Which of the above quantities can be measured using a vector voltmeter ?

(a) 1 and 3 only (b) 1, 2 and 4
(c) 1, 2 and 3 (d) 3 and 4

78. Replace the below shown circuit by a single voltage source in series with an impedance.

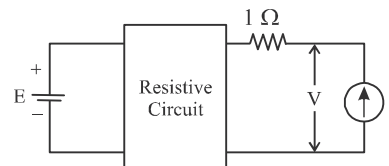


(a) 2 V, 1 Ω (b) 1 V, 3 Ω
(c) 3 V, 1 Ω (d) 2 V, 3 Ω

79. A barium titanate crystal has a thickness of 2 mm. Its voltage sensitivity is $12 \times 10^{-3} \text{ Vm/N}$. It is subjected to a pressure of 0.5 MN/m². What is the voltage generated?

(a) 3 V (b) 6 V
(c) 5 V (d) 12 V

80. For the circuit as shown below, if $E = E_1$ and I is removed, then $V = 5$ volts. If $E = 0$ and $I = 1 \text{ A}$, then $V = 5$ volts. For $E = E_1$ and I replaced by a resistor of 5 Ω , what is the value of V in volts?



(a) 5.0 (b) 2.5
(c) 7.5 (d) 3.5

81. The impulse response of a second-order under-damped system started from rest is given by:

$$c(t) = 12.5 e^{-6t} \sin 8t, t \geq 0$$

What are the natural frequency and the damping factor of the system respectively?

(a) 10 and 0.6 (b) 10 and 0.8
(c) 8 and 0.6 (d) 8 and 0.8

82. What will be the type of the system, if the steady state performance of control system yields a non-zero finite value of the velocity error constant?

- (a) type - 0 (b) type - 1
(c) type - 2 (d) type - 3

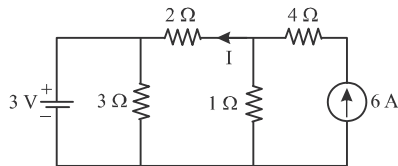
83. On which of the following factors does hysteresis loss not depends?

- (a) Magnetic field intensity
(b) Frequency of the field
(c) Volume of the material
(d) Neal temperature

84. A strain gauge having a resistance of 500 ohm and a gauge factor 3.0 is bonded on a member of structure undergoing tensile stress. If the change in resistance of the gauge is accurately measured as 1.5 ohm, what is the value of strain suffered by the member?

- (a) 0.01 (b) 0.001
(c) 0.1 (d) 0.003

85. For the circuit as shown below, what is the value of I?



- (a) 4 A (b) 3 A
(c) 2 A (d) 1 A

86. Dissipation factor, $\tan\delta$, of a capacitor is measured by which bridge?

- (a) Anderson bridge (b) Hay bridge
(c) Schering bridge (d) Wien bridge

87. The characteristic equation of a feedback control system is given by:

$$s^3 + 6s^2 + 9s + 4 = 0$$

What is the number of roots in the left-half of the s-plane?

- (a) Three (b) Two
(c) One (d) Zero

88. Which one of the following is not a Maxwell's equation?

- (a) $\nabla \times H = (\sigma + j\omega\epsilon) E$
(b) $F = Q(E + v \times B)$
(c) $\oint_C H \cdot ds = \int_s J \cdot ds + \frac{\partial D}{\partial t} \cdot ds$
(d) $\oint_s B \cdot ds = 0$

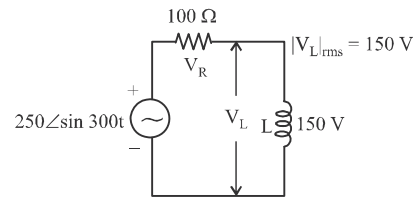
89. The unit step response of a system is $[1 - e^{-t}(1 + t)] u(t)$. What is the nature of the system in turn of stability?

- (a) Unstable (b) Stable
(c) Critically stable (d) Oscillatory

90. A D' Arsonval galvanometer, 1 mA, 50 ohm is to be converted to a 5 Amp-ammeter. What is the value of the shunt resistor, Rsh?

- (a) 10 ohm (b) 1 ohm
(c) 0.01 ohm (d) 100 ohm

91. Consider the following, with respect to the circuit as shown below:



1. $V_R = 100\sqrt{2} V$
2. $|I|_{rms} = 2 A$
3. $L = 0.25 H$

Which of the above statements is/are correct?

- (a) 1 only (b) 2 and 3
(c) 1 and 3 (d) 1 and 2

92. Consider the following statements in connection with boundary relations electric field:

1. In a single medium electric field is continuous.
2. The tangential components are the same on both sides of a boundary between two dielectrics.
3. The tangential electric field at the boundary of a dielectric and a current carrying conductor with finite conductivity is zero.
4. Normal component of the flux density is continuous across the charge-free boundary between two dielectrics.

Which of the above statements is/are correct?

- (a) 1 only (b) 1, 2 and 3
(c) 1, 2 and 4 (d) 3 and 4 only

93. Consider the following:

1. Phase margin
2. Gain margin
3. Maximum overshoot
4. Bandwidth

Which of the above are the frequencydomain specification required to design a control system?

- (a) 1 and 2 only (b) 1 and 3 only
(c) 1, 3 and 4 (d) 1, 2 and 4

94. A 0 to 300 V voltmeter has an error of $\pm 2\%$ of fsd. What is the range of readings if true voltage is 30 V?

- (a) 24 V - 36 V
(b) 20 V - 40 V
(c) 29.4 V - 30.6 V
(d) 20 V - 30 V

95. A network function $Z(s) = \frac{V(s)}{I(s)}$ has a signal pole at

$$s = -\frac{1}{\sqrt{3}} \text{ and a single zero } s = -\sqrt{3}. \text{ If the excitation } v(t) =$$

$\sin t$, then what is the angle of lead or lag of the current?

- (a) Lead the voltage by 30°
(b) Lag the voltage by 30°
(c) Lead the voltage by 90°
(d) Lag the voltage by 90°

96. Magnetically hard materials do not possess which of the following characteristics?
 (a) High retentivity
 (b) High coercivity
 (c) Strong magnetic reluctance
 (d) Zero differential permeability
97. In a digital voltmeter, the oscillator frequency is 400 kHz. The ramp voltage falls from 8 V to 0 V in 20 ms. What is the number of pulses counted by the counter?
 (a) 8000 (b) 4000
 (c) 3200 (d) 1600
98. If the current flowing through a 20 ohm resistor is given as,
 $i(t) = 4 + 5 \sin \omega t - 3 \cos 3\omega t$ amp, then what is the power consumed by the resistor?
 (a) 1000 W (b) 660 W
 (c) 500 W (d) 180 W ± 20
99. What is the error in magnitude at the corner frequency for an asymptotic Bode magnitude plot for the term $(1 + s\tau)^{\pm n}$?
 (a) $\pm 20 \text{ n db}$ (b) $\pm 6 \text{ n db}$
 (c) $\pm 3 \text{ n db}$ (d) $\pm 1 \text{ n db}$
100. Quartz and BaTiO_3 exhibit which of the following properties?
 (a) Magnetostriction (b) Ferromagnetism
 (c) Piezoelectricity (d) Ferroelectricity

ANSWER KEYS

1. (c)	2. (a)	3. (a)	4. (a)	5. (c)	6. (c)	7. (b)	8. (d)	9. (b)	10. (a)
11. (a)	12. (a)	13. (c)	14. (a)	15. (a)	16. (b)	17. (d)	18. (c)	19. (d)	20. (d)
21. (c)	22. (b)	23. (c)	25. (c)	26. (a)	27. (a)	28. (b)	29. (c)	30. (c)	31. (a)
32. (c)	33. (b)	34. (d)	35. (a)	36. (c)	37. (d)	38. (b)	39. (d)	40. (d)	41. (c)
42. (c)	43. (c)	44. (d)	45. (d)	46. (d)	47. (b)	48. (b)	49. (a)	50. (b)	51. (d)
52. (d)	53. (b)	54. (c)	55. (a)	56. (a)	57. (c)	58. (d)	59. (c)	60. (b)	61. (c)
62. (b)	63. (a)	64. (b)	65. (b)	66. (b)	67. (a)	68. (a)	69. (c)	70. (b)	71. (d)
72. (a)	73. (a)	74. (d)	75. (b)	76. (b)	77. (c)	78. (c)	79. (b)	80. (b)	81. (a)
82. (b)	83. (d)	84. (b)	85. (d)	86. (c)	87. (a)	88. (b)	89. (c)	90. (c)	91. (b)
92. (c)	93. (d)	94. (a)	95. (a)	96. (a)	97. (a)	98. (b)	99. (c)	100. (c)	

TEST PAPER 4

1. Consider the following:

1. Oscillator
2. Emitter follower
3. Cascaded amplifier
4. Power amplifier

Which of these use feedback amplifiers?

(a) 1 and 2	(b) 1 and 3
(c) 2 and 4	(d) 3 and 4

2. Why npn transistors are preferred over pnp transistors?

- (a) Leakage current in npn transistors is less than pnp transistors
- (b) Mobility of majority carrier in npn transistors is greater than the mobility of majority carrier in pnp transistors
- (c) Bias voltage required in npn is less than in pnp transistors
- (d) Bias voltage required in npn is greater than in pnp transistors

3. Consider the following statements:

To draw A.C. equivalent circuit of a transistor, all

1. A.C. sources are shorted
2. A.C. sources are shorted
3. A.C. sources are opened
4. A.C. sources are connected to D.C. source

which of the above statements is/are correct

(a) 2 and 4	(b) 1 and 2
(c) 1 only	(d) 3 and 4

4. Which one of the following statement is **not** correct with regard to power amplifiers?

- (a) The collector current is large
- (b) They are used as the front end of the multi stage amplifiers
- (c) They are used near the end of the multi stage amplifiers
- (d) They have a high power rating $> \frac{1}{2} W$

5. Consider the following statements regarding the class B power amplifier (Complementary symmetry type)

1. The efficiency of the amplifier is higher than that of class A amplifier
2. The power output is low
3. Cross over distortion is present.
4. The standby power dissipation is absent.

Which of the above statements are correct /

(a) 1, 2 and 3	(b) 1, 2 and 4
(c) 1, 3 and 4	(d) 2, 3 and 4

6. Consider the following:

1. Distortion
2. Gain
3. Bias stabilization
4. Sensitivity
5. Frequency response

Which of these properties of the power amplifier one should concentrate upon while designing a good power amplifier circuit?

(a) 1, 2 and 3	(b) 1, 3 and 5
(c) 2, 3 and 4	(d) 4 and 5

7. Consider the following:

1. Coupling capacitor
2. Emitter bypass capacitor
3. Emitter to base diffusion capacitance of the BJT
4. Stray capacitance of the circuit.

Which of these components in a R C coupled amplifier control the lower cut off frequency of the amplifier?

(a) 1 and 2	(b) 2 and 3
(c) 3 and 4	(d) 1 and 4

8. Which one of the following is a regulated power supply?

(a) IC 555	(b) IC 844
(c) IC 3080	(d) IC 723

9. Consider the following statements regarding an OP AMP:

1. All types of negative feedback reduce non linear distortion.
2. All types of negative feedback reduce the output offset voltage.
3. Non inverting (Current and voltage) feedback increases the input impedance.
4. Inverting (Current and voltage) feedback decreases input impedance.

Which of the above statements are correct?

(a) 1 only	(b) 2 and 3 only
(c) 2 and 4 only	(d) 1, 2, 3 and 4

10. Consider the following statements:

The bias stability of an emitter bias amplifier circuit improves by

1. Decreasing the value of R_B .
2. Increasing the value of R_E .
3. Decreasing the value of R_E .
4. Increasing the value of R_B .
5. Increasing the value of R_C .

Which of the above statements are correct?

(a) 1 and 2	(b) 2 and 3
(c) 3 and 4	(d) 4 and 5

11. Which of the following will be true for a CE transistor amplifier if the emitter resistor value is made equal to zero?

1. Its gain will increase
2. Its stability will increase
3. Its gain will decrease
4. Its stability will decrease.

Select the correct answer from the codes given below:

(a) 1 and 2	(b) 2 and 3
(c) 3 and 4	(d) 1 and 4

12. Which one of the following circuits is used for converting a sine wave into a square wave?
 (a) Astable multivibration
 (b) Monostable multivibration
 (c) Bistable multivibration
 (d) Schmitt trigger
13. Which of the transistor models is most preferred for the analysis of a transistor circuit both at mid band and at high frequencies?
 (a) h parameter model (b) y parameter model
 (c) s parameter model (d) hybrid π model
14. Which of the following describe the correct properties of an emitter follower circuit?
 1. It is a voltage series feedback circuit
 2. It is a current series feedback circuit
 3. Its voltage gain is less than unity
 4. Its output impedance is very low.
 Select the correct answer from the code given below:
 (a) 1, 3 and 4 (b) 2, 3 and 4
 (c) 2 and 3 only (d) 2 and 4 only
15. Which one of the following type of negative feedback increases the input resistance and decreases the output resistance of an amplifier?
 (a) Current series feedback
 (b) Voltage series feedback
 (c) Current shunt feedback
 (d) Voltage shunt feedback
16. Which one of the following oscillators is well suited for the generation of wide range audio frequency sine waves?
 (a) RC phase shift oscillator
 (b) Wien bridge oscillator
 (c) Colpitts oscillator
 (d) Hartley oscillator
17. Consider the following statements about a good power supply
 1. The a.c. ripple should be high.
 2. S_v (Voltage stability factor) should be low
 3. S_T (Temperature stability factor) should be low
 Which of the above statements are correct?
 (a) 1, 2 and 3 (b) 2 only
 (c) 3 only (d) 2 and 3 only
18. Which of the following are the non-linear applications of OP amp?
 1. Current-to-voltage converter.
 2. Comparator
 3. Peak detector
 4. Limiter
 Select the correct answer from the codes given below:
 (a) 1, 2 and 3 (b) 2, 3 and 4
 (c) 1, 3 and 4 (d) 1, 2 and 4
19. Consider a 565 PLL with $R_T = 10\text{ k}\Omega$ and $C_T = 0.01\text{ }\mu\text{F}$. What is the output frequency of the V_{CO} ?
 (a) 10 kHz (b) 5 kHz
 (c) 2.5 kHz (d) 1.25 kHz
20. Which of the following does not show non-linear V-I characteristics?
 (a) Schottky diode
 (b) Tunnel diode
 (c) Thermistor, at a fixed temperature
 (d) p - n junction diode
21. Which of the following conditions must be satisfied for a transistor to remain under saturation?
 1. Its collector to base junction should be under forward bias.
 2. Its collector to base junction should be under reverse bias.
 3. Its emitter to base junction should be under reverse bias.
 4. Its emitter to base junction should be under forward bias.
 Select the correct answer from the codes given below:
 (a) 1 and 2 (b) 1 and 3
 (c) 2 and 3 (d) 1 and 4
22. Which of the following Boolean algebra rules is correct?
 (a) $A \cdot A = 1$ (b) $A + \overline{A}B = A + B$
 (c) $A + AB = A + B$ (d) $A(A + B) = B$
23. What are the ultimate purposes of minimizing logic expressions?
 1. To get a small size expression.
 2. To reduce the number of variables in the given expression.
 3. To implement the function of the logic expression with least hardware.
 4. To reduce the expression for making it feasible for hardware implementation.
 Select the correct answer from the codes given below:
 (a) 1 only (b) 2 and 3
 (c) 3 only (d) 3 and 4
24. Which of the following factors are responsible to design IC logic gates to operate at a fixed supply voltage of 5 volts?
 1. Low heating of IC logic gates.
 2. Compatibility with other logic gates.
 3. Satisfactory and safe operation.
 4. Standardization from IC manufacturing point of view.
 Select the correct answer from the codes given below:
 (a) 1 only (b) 2 only
 (c) 2 and 3 (d) 3 and 4
25. Which of the following statements is not correct?
 (a) Propagation delay is the time required for a gate to change its state.
 (b) Noise immunity is the amount of noise which can be applied to the input of a gate without causing the gate to change state
 (c) Fan in of a gate is always equal to fan out of the same gate.
 (d) Operating speed is the maximum frequency at which digital data can be applied to a gate.
26. Which junction has least junction capacitance?
 (a) Alloy (b) Grown
 (c) Diffused (d) Point contact
27. Which of the following are universal gates?
 1. NAND
 2. NOR
 3. XOR

Select the correct answer from the codes given below:

- (a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

28. Which of the following output configurations are available in a TTL gate?

1. Open collector output
2. Totem pole output
3. Tristate output

Select the correct, answer form the code given below:

- (a) 1 only (b) 1 and 2 only
(c) 2 and 3 only (d) 1, 2 and 3

29. Which one of the following logic families can be operated using a supply voltage from 3 V to 15 V?

- (a) TTL (b) ECL
(c) PMOS (d) CMOS

30. Which of the following circuits come under the class of combinational logic circuits?

1. Full adder 2. Full subtractor
3. Half adder 4. J-K flip flop
5. Counter

Select the correct answer from the codes given below:

- (a) 1 only (b) 3 and 4
(c) 4 and 5 (d) 1, 2 and 3

31. Consider a multiplexer with X and Y as data inputs and Z as control input. $Z = 0$ selects input X and $Z = 1$ selects input Y. What are the connections required to realize the 2-variable Boolean function $f = T + R$, without using any additional hardware?

- (a) R to X, 1 to Y, T to Z
(b) T to X, R to Y, T to Z
(c) T to X, R to Y, 0 to Z
(d) R to X, 0 to Y, T to Z

32. With which decoder it is possible to obtain many code conversions?

- (a) 2 line to 4 line
(b) 3 line to 8 line
(c) not possible with any decoder
(d) 4 line to 16 line decoder

33. Match list I with list II and select the correct answer using the codes given below the lists:

List I

(Application of circuit)

- A. Divider
B. Clips input voltage at two predetermined levels
C. Square wave generator
D. Narrow current pulse generator

List II

(Circuit name)

1. Astable multivibrator
2. Schmitt trigger
3. Bistable multivibrator
4. Blocking oscillator

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	3	2	1	4
(c)	4	1	2	3
(d)	3	1	2	4

34. Consider the following statements:

For a master slave J - K flip flop,

1. the toggle frequency is the maximum clock frequency at which the flip flop will toggle reliably
2. the data input must precede the clock triggering edge transition time by some minimum time
3. the data input must remain fixed for a given time after, the clock triggering edge transition time for reliable operation.
4. propagation delay time is equal to the rise time and fall time of the data.

Which of the above statements is/are correct?

- (a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 3 and 4 only

35. Consider the following statements:

1. A flip flop is used to store 1 bit of information
2. Race around condition occurs in a J K flip flop when both the inputs are 1.
3. Master slave configuration is used in flip flops to store 2 bits of information.
4. A transparent latch consists of a D type flip flop.

Which of the above statements is are correct?

- (a) 1 only (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 2 and 3 only

36. Which of the following flip flop is used as a latch

- (a) J k flip flop (b) R S flip flop
(c) T flip flop (d) D flip flop

37. Which of the following conditions should be satisfied to call an astable multivibrator circuit using discrete components as a digital circuit?

1. A flip flop is always a digital circuit.
2. Only when we assign 1 and 0 to the high and low levels of the output, a flip flop is called a digital circuit.
3. Only if the power supply voltage is maintained at + 5 V or - 5V, it is called a digital circuit.
4. Only if it is in IC form, following the technology of IC manufacture, it is called a digital circuit. Select the correct answer from the codes given below:

- (a) 1 only (b) 2 and 3
(c) 2 only (d) 3 and 4

38. Which of the following circuits come under the class of sequential logic circuits?

1. Full adder 2. Full subtractor
3. Half adder 4. J -K flip flop
5. Counter

Select the correct from the correct given below:

- (a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 4 and 5

39. Consider the following statements regarding registers and latches:

1. Register are made of edge triggered FFs. Whereas latches made from level triggered FFs
2. Registers are temporary storage device whereas latches are not.
3. A latch employs cross couple feedback connections.
4. A register stores a binary word whereas a latch does not.

Which of the above statements is are/correct?

- (a) 1 only (b) 1 and 3
(c) 2 and 3 (d) 3 and 4

40. Which of the following capabilities available in a Universal Shift Register?

1. Shift left
2. Shift right
3. Parallel load
4. Serial add

Select the correct answer from the correct given below:

- (a) 2 and 4 only (b) 1, 2 and 3
(c) 1, 2 and 4 (d) 1, 3 and 4

41. Which of the following measurements can be done using a counter?

1. Pulse duration
2. Interval between two pulses
3. Amplitude of the pulse
4. Rise time of a pulse

Select the correct answer from the codes given below:

- (a) 1 and 2 (b) 2 and 3
(c) 1 and 4 (d) 2 and 4

42. Match list I with list II and select the correct answer using the code given below the lists:

List I

(Type of N-bit ADC)

- A. Flash converter
B. Successive approximation
C. Counter ramp
D. Dual slope

List II

(Characteristics)

1. Integrating Type
2. Fastest converter
3. Maximum conversion time = N bits
4. Uses an DAC in its feedback path

	A	B	C	D
(a)	2	3	4	1
(b)	1	3	4	2
(c)	2	4	3	1
(d)	1	4	3	2

43. In which one of the following types of analog to digital converters, the conversion time is practically independent of the amplitude of the analog signal?

- (a) The dual slope integrating type
(b) Successive approximation type
(c) Counter ramp type
(d) Tracking type

44. Consider the function $F(s) = \frac{\omega}{s^2 + \omega^2}$

where $F(s)$ is the Laplace transform of $f(t)$. What is the steady state value of $f(t)$.

- (a) Zero (b) one
(c) two (d) A value between -1 and +1

45. The transfer function of a linear time invariant system is given as $\frac{1}{(s+1)}$. What is the steady state value of the unit impulse response?

- (a) Zero (b) One
(c) Two (d) Infinite

46. What is the characteristic of a good control system?

- (a) Sensitive to parameter variation
(b) Insensitive to input command
(c) Neither sensitive to parameter variation nor sensitive to input commands
(d) Insensitive to parameter variation but sensitive to input commands.

47. How can the bandwidth of a control system be increased?

- (a) By the use of phase lead network.
(b) By the use of phase lag network.
(c) By the use of both phase lag and phase lead network.
(d) By the use of cascaded amplifiers in the system.

48. Which of the following may result in instability problem?

- (a) Large error (b) High selectivity
(c) High gain (d) Noise

49. A negative feedback closed loop system is supplied to an input of 5 V. The system has a forward gain of 1 and a feedback gain of 1. What is the output voltage?

- (a) 1.0 V (b) 1.5 V
(c) 2.0 V (d) 2.5 V

50. For what positive value of K does the polynomial

$$s^4 + 8s^3 + 24s^2 + 32s + K = 0$$

have roots with zero real parts?

- (a) 10 (b) 20
(c) 40 (d) 80

51. How many roots with positive real parts do the equation $s^3 + s^2 - s + 1 = 0$ have?

- (a) Zero (b) One
(c) Two (d) Three

52. The characteristic equation of a control system is given as

$$s^4 + 8s^3 + 24s^2 + 32s + K = 0$$

What is the range of values of K for this system to be stable?

- (a) $0 \leq K < 80$ (b) $0 \leq K < 100$
(c) $0 \leq K < 300$ (d) $0 \leq K < 600$

53. Consider the equation

$$s^3 + 2s + K(s+2) = 0.$$

Where do the roots of this equation break on the root loci plot?

- (a) -3.414 (b) -2.414
(c) -1.414 (d) -0.414

54. How many number of branches the root loci of the equation $s(s+2)(s+3) + K(s+1) = 0$ have?

- (a) Zero (b) One
(c) Two (d) Three

55. The characteristic equation of a control system is given as $s^4 + 4s^3 + 4s^2 + 3s + K = 0$.
What is the value of K for which this system is marginally stable?
- (a) $\frac{9}{16}$ (b) $\frac{19}{16}$
(c) $\frac{29}{16}$ (d) $\frac{39}{16}$
56. Which of the following can be used as a tachogenerator in control systems?
(a) Microsyn (b) DC servomotor
(c) AC servomotor (d) Magnetic amplifier
57. The transfer function of a controller is given as $K_p + K_d s$ where K_p and K_d are constants. What type of controller is this?
(a) Proportional
(b) Proportional plus integral
(c) Proportional plus derivative
(d) Integral plus derivative
58. The transfer function of a controller is given as $K_d K_p + K_d \cdot s + \frac{K_i}{s}$ where K_p , K_d and K_i are constants. What type of controller is this?
(a) Proportional
(b) Proportional plus derivative
(c) Proportional plus integral
(d) Proportional plus integral plus derivative.
59. In closed loop control system, what is the sensitivity of the gain of the overall system, M to the variation in G?
(a) $\frac{1}{1+G(s)H(s)}$ (b) $\frac{1}{1+G(s)}$
(c) $\frac{G(s)}{1+G(s)H(s)}$ (d) $\frac{G(s)}{1+G(s)}$
60. Which of the following statements about the matched filter in a communication receiver are correct?
1. Its impulse response depends on the signal shape.
2. It maximizes the SNR at the detection instant.
3. It produces ISI.
4. It may produce phase error if synchronization is improper.
Select the correct answer from the codes given below:
(a) 1 and 4 only (b) 1 and 2 only
(c) 2, 3 and 4 (d) 1, 2 and 4
61. A single mode fibre does not suffer from which type of dispersion?
(a) Waveguide dispersion
(b) Material dispersion
(c) Intermodal dispersion
(d) Polarization mode dispersion
62. A balanced modulator is used in the generation of which of the following?
(a) DSB - SC signal (b) FM signal
(c) PM signal (d) PAM signal
63. An amplitude modulated signal occupies a frequency range from 395 kHz to 405 kHz. It can be demodulated by which of the following?
(a) Using an envelope detector and filter.
(b) Multiplying with a 395 kHz local signal
(c) Multiplying with a 405 kHz local signal
(d) Low pass filtering with cut off at 400 kHz.
64. An audio signal is band limited to 4 kHz. It is sampled at 8 kHz. What will be the spectrum of the sampled signal?
(a) - 4 kHz to 4 kHz
(b) - 8 kHz to 8 kHz
(c) every 4n kHz and repeating
(d) every ± 8 kHz and repeating as well as at zero (k integer)
65. A signal occupies a band 5 kHz to 10 kHz. For proper error free reconstruction at what rate it should be sampled?
(a) 10 kHz (b) 20 kHz
(c) 5 kHz (d) $-(10 +) \times 2$ kHz
66. The spectral range of a band pass signal extends from 10 MHz to 10.4 MHz. What is the minimum sampling frequency required for reconstruction?
(a) 20 MHz (b) 20.8 MHz
(c) 20.4 MHz (d) 0.8 MHz
67. An audio signal is to be transmitted digitally. Which is the system best suited for good fidelity?
(a) 8 bit PCM
(b) 13 bit PCM
(c) 32 bit PCM
(d) PCM system with non uniform quantizer.
68. For good quality signal transmission all frequency components should have the same transmission delay, t_d and same phase shift ϕ_s . What can be said about the statement?
(a) Correct
(b) True for t_d but not for ϕ_s
(c) Not true for t_d but true for ϕ_s
(d) Both t_d and ϕ_s are not involved in quality.
69. Which of the following introduces mode partition noise?
(a) Coaxial line t_d
(b) Wave guide
(c) Fibre transmission line
(d) Both coaxial line and wave guide.
70. Which of the following does not cause losses in optical fibre cables?
(a) Impurities
(b) Microbending
(c) Attenuation in glass
(d) Stepped index operation
71. On which bands do the optical fibres operate?
1. Ultra violet band
2. Ultra high frequency band
3. Visible light band
4. Infra red band

Select the correct answer from the codes given below:

- (a) 1 only (b) 1 and 2 only
(c) 1, 2 and 3 (d) 1,3 and 4
72. Which one of the following photodetector does not provide gain?
(a) Photo transistor
(b) Photo conductor
(c) Avalanche photodiode
(d) p - i - n photodiode
73. Consider the following statements:
In the case of space wave propagation the signal strength at the receiver is
1. Directly proportional to transmitter and receiver heights.
2. Inversely proportional to distance between transmitter and receiver.
3. Directly proportional to frequency.
Which of the above statements is are correct?
(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 3 only
74. What was the first commercial geostationary communication satellite?
(a) INTELSAT 1 (b) ECHO
(c) INSAT -1A (d) SPUTNIK
75. What does a link budget for satellite communication include?
(a) Total cost of satellite
(b) Cost of satellite plus launch vehicle
(c) Signal and noise levels in dB
(d) Margins of error permitted.
76. Which one of the following is a transferred electron device?
(a) BARITT diode (b) IMPATT diode
(c) TRAPATT diode (d) Gunn diode
77. Consider the transmission line of length 37.5cm. which is terminated into zero resistance. This line is being excited by a source of 1 GHz which has an internal impedance of 50 Ω . What is the input impedance of the line as seen by the source?
(a) 50 Ω (b) Zero Ω
(c) 100 Ω (d) Infinite Ω
78. Which of the following is a microwave source with a 'cross field' structure?
(a) Double cavity klystron
(b) Reflex klystron
(c) Magnetron
(d) Travelling wave tube
79. Which of the following device has the 'negative resistance' characteristic?
(a) Reflex klystron (b) Gunn diode
(c) P - N - P transistor (d) Magnetron
80. Which of the following devices is a 'hot electron' diode?
(a) Thermionic tube diode
(b) Schottky Barrier diode
(c) Thomsomn Deletion diode
(d) Thermal electron diode.
81. Which of the following uses 'transferred electron effect' for production of microwaves?
(a) Silicon
(b) Germanium
(c) Metal semiconductor Junction
(d) Gallium Aresenide
82. Which of the following is a microwave power amplifier?
(a) Gunn diode
(b) Reflex klystron
(c) Magnetron
(d) Travelling wave tube
83. Consider the following statements:
The klystron and travelling wave tube differ from each other,
1. In TWT the microwave circuit is non resonant
2. In Klystron the microwave circuit is resonant.
3. TWT uses attenuator.
4. The wave in TWT is a non propagating wave
Which of the above statements are correct?
(a) 1 and 2 only (b) 3 and 4 only
(c) 1, 2 and 3 (d) 2,3 and 4
84. Which device can detect the presence of both forward and backward waves in a waveguide?
(a) Filter (b) Detector
(c) Directional coupler (d) Magic T
85. Which of the following modes can exist in a rectangular wave guide?
(a) TM_{10} (b) TE_{10}
(c) TM_{00} (d) TM_{01}
86. Which of the following does not apply to Yagi Uda antenna
(a) High gain
(b) Reasonably good bandwidth
(c) Folded dipole
(d) Parasitic elements
87. Which of the following antenna is obtained by modifying a wave guide?
(a) Microstrip Antenna
(b) Helical Antenna
(c) Horn Antenna
(d) Dipole Antenna
88. Which of the following is a circularly polarized antenna?
(a) Horn (b) Dipole
(c) Helical (d) Pyramidal
89. Which of the following antennas uses a number of varying length parallel elements?
(a) Helical antenna
(b) Pyramidal Horn
(c) Corner reflection antenna
(d) Yagi - Uda antenna.

90. The following components are used to measure power output of a 2 kW TWT amplifier:

1. TWTA
2. Low/pass /high pass filter
3. 20 dB attenuator
4. 40 dB directional coupler with matched load
5. power meter

What is the correct sequence of connection of these components?

- (a) 2 - 4 - 1 - 3 - 5
- (b) 1 - 3 - 4 - 2 - 5
- (c) 1 - 2 - 4 - 3 - 5
- (d) 2 - 4 - 1 - 5 - 3

91. Match list I with list II and select the correct answer using the code given below the Lists:

List I (Microwave Measuring instruments)	List II (Measurements effected)
A. Bolometer	1. Reflection coefficients
B. VSWR meter	2. Half power beam widths
C. Cavity wave meter	3. Microwave Power
D. Pattern recorder	4. Microwave frequency

Codes:

A	B	C	D
(a) 2	1	4	3
(b) 3	1	4	2
(c) 2	4	1	3
(d) 4	3	1	2

92. Which one of the following statements is correct?
- (a) AGC in radio receivers will keep the total signal output fairly constant but the noise component will be reduced ; with the result the $\frac{S}{N}$ ratio will improve.
 - (b) AGC in radio receivers is a linear operation w. r. t. both signals and noise.
 - (c) Sudden changes in the output while tuning, which may cause damage to the components, is an unavoidable feature of AGC.
 - (d) AGC operation is independent of the filter components used in AGC circuit.
93. Consider the following statements:
1. Taking 2's complement is equivalent to sign change.
 2. In the 2's complement representation the most significant bit (MSB) is zero for a positive number
 3. In a 4 bit binary representation of a binary number A, A + 1's complement of A = 2^4

Which of the above statements are correct?

- (a) 1 and 2 only
- (b) 1 and 3 only
- (c) 2 and 3 only
- (d) 1, 2 and 3

94. Consider the following statements:

1. Strictly speaking C supports one-dimensional arrays only.
2. An array element may be an array by itself.
3. Array elements need not occupy contiguous memory locations.

Which of the above statements is/are correct?

- (a) 1 only
- (b) 2 only
- (c) 1 and 2
- (d) 2 and 3

95. What can be the maximum dimension of an array in C language program?

- (a) 3
- (b) 4
- (c) 5
- (d) It is compiler dependent

96. With reference to C programming language, which of the following statements are correct?

1. An identifier may start with an underscore.
2. An identifier may end with an underscore.
3. IF is a valid identifier.
4. The number of significant characters in an identifier is implementation dependent.

Select the correct answer from the codes given below:

- (a) 1 and 2 only
- (b) 2 and 3 only
- (c) 1, 2, 3 and 4
- (d) 3 and 4 only

97. How many distinct binary trees can be constructed with three nodes?

- (a) 1
- (b) 2
- (c) 3
- (d) 5

98. Consider the following statements:

1. Internal sorting is used if the number of items to be sorted is very large.
2. External sorting is used if the number of items to be sorted is very large.
3. External sorting needs auxiliary storage.
4. Internal sorting needs auxiliary storage.

Which of the above statements are correct?

- (a) 1 and 2
- (b) 2 and 3
- (c) 3 and 4
- (d) 2 and 4

99. Which of the following has a major role in implementation of function calls in C?

- (a) Processor's registers
- (b) Data segment
- (c) The heap
- (d) System stack

100. Which one of the following algorithms design techniques is used in quick sort algorithm?

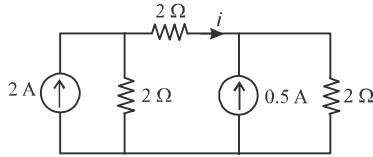
- (a) Dynamic programming
- (b) Backtracking
- (c) Divide and conquer
- (d) Greedy

ANSWER KEYS

1. (a)	2. (b)	3. (c)	4. (c)	5. (c)	6. (a)	7. (a)	8. (d)	9. (d)	10. (a)
11. (d)	12. (d)	13. (d)	14. (a)	15. (b)	16. (b)	17. (d)	18. (b)	19. (a)	20. (c)
21. (d)	22. (c)	23. (d)	24. (c)	25. (c)	26. (d)	27. (a)	28. (d)	29. (d)	30. (d)
31. (a)	32. (d)	33. (d)	34. (a)	35. (c)	36. (d)	37. (a)	38. (d)	39. (b)	40. (b)
41. (a)	42. (a)	43. (b)	44. (b)	45. (a)	46. (d)	47. (a)	48. (c)	49. (d)	50. (d)
51. (c)	52. (a)	53. (a)	54. (d)	55. (d)	56. (c)	57. (c)	58. (d)	59. (b)	60. (b)
61. (c)	62. (a)	63. (d)	64. (c)	65. (a)	66. (d)	67. (d)	68. (d)	69. (b)	70. (d)
71. (d)	72. (d)	73. (b)	74. (a)	75. (c)	76. (d)	77. (d)	78. (c)	79. (b)	80. (b)
81. (d)	82. (d)	83. (c)	84. (c)	85. (b)	86. (b)	87. (c)	88. (c)	89. (d)	90. (b)
91. (b)	92. (c)	93. (a)	94. (b)	95. (d)	96. (c)	97. (d)	98. (b)	99. (d)	100. (c)

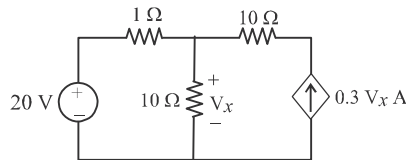
TEST PAPER 5

1. The current i in is



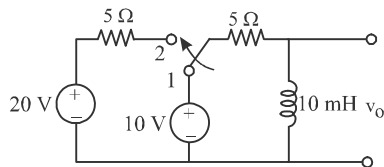
- (a) 0.5 A (b) 5/6 A
(c) 1.5 A (d) 2.5 A

2. In figure, the voltage source



- (a) delivers 200/3 W
(b) absorbs 100 W
(c) delivers 100 W
(d) absorbs 200/3 W

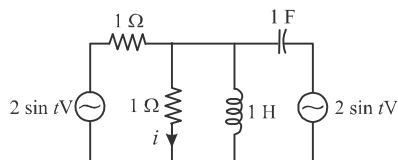
3. The switch shown in figure is ideal and has been in position 1 for $t < 0$



If the switch is moved to position 2 at a $t = 0$, then v_o for $t > 0$ is given by

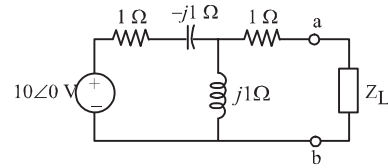
- (a) 0 V (b) $2 + 2(-e^{-1000t})$ V
(c) $2(1 - e^{-1000t})$ V (d) $2(1 - e^{-1000t})$ V

4. The current i in figure is



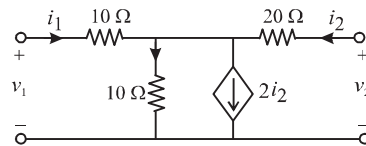
- (a) $\sqrt{2} \sin(t + 45^\circ)$ A
(b) $\sqrt{2} \sin(t - 45^\circ)$ A
(c) $2 \sin(t + 45^\circ)$ A
(d) $2 \sin(t - 45^\circ)$ A

5. For the circuit given in figure in order to obtain maximum power transfer, the load Z_L (in Ω) should be



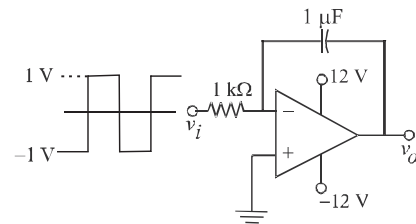
- (a) $1 - j$ (b) $1 + j$
(c) $2 - j$ (d) $-j$

6. The h_{21} parameter of the two port network shown in figure is



- (a) -1/3 (b) -1
(c) 1/3 (d) 2

7. The input v_i to the circuit shown in figure is a square wave of amplitude ± 1 V and frequency 100 Hz.



Assuming ideal components, the peak-to-peak amplitude of the output is v_o is

- (a) 2 V (b) 5 V
(c) 10 V (d) 12 V

8. A network has 8 branches and 5 nodes. The fundamental loop matrix B of the network is

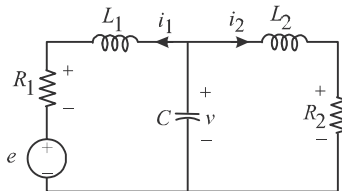
$$B = \begin{bmatrix} -1 & 0 & 0 & 0 & -1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & -1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 0 & -1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & -1 & 1 & 0 \end{bmatrix}$$

The fundamental cut-set matrix Q of the same network is

$$(a) \begin{bmatrix} -1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & -1 & 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & -1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

- (b)
$$\begin{array}{ccccccc} \neg & 1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \neg \\ -1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & \\ 0 & -1 & -1 & -1 & 0 & 0 & 1 & 0 & \\ \equiv & 0 & -1 & -1 & 0 & 0 & 0 & 0 & 1 \Downarrow \\ \neg & 1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \neg \\ 1 & -1 & -1 & -1 & 0 & 1 & 0 & 0 & \\ 0 & 1 & 1 & 1 & 0 & 0 & 1 & 0 & \\ \equiv & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \Downarrow \\ \neg & 1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \neg \\ -1 & 1 & -1 & 1 & 0 & 1 & 0 & 0 & \\ 0 & -1 & -1 & -1 & 0 & 0 & 1 & 0 & \\ \equiv & 0 & -1 & -1 & 0 & 0 & 0 & 0 & 1 \Downarrow \end{array}$$
- (c)
$$\begin{array}{ccccccc} \neg & 1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \neg \\ 1 & -1 & -1 & -1 & 0 & 1 & 0 & 0 & \\ 0 & 1 & 1 & 1 & 0 & 0 & 1 & 0 & \\ \equiv & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \Downarrow \\ \neg & 1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \neg \\ -1 & 1 & -1 & 1 & 0 & 1 & 0 & 0 & \\ 0 & -1 & -1 & -1 & 0 & 0 & 1 & 0 & \\ \equiv & 0 & -1 & -1 & 0 & 0 & 0 & 0 & 1 \Downarrow \end{array}$$
- (d)
$$\begin{array}{ccccccc} \neg & 1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \neg \\ -1 & 1 & -1 & 1 & 0 & 1 & 0 & 0 & \\ 0 & -1 & -1 & -1 & 0 & 0 & 1 & 0 & \\ \equiv & 0 & -1 & -1 & 0 & 0 & 0 & 0 & 1 \Downarrow \end{array}$$

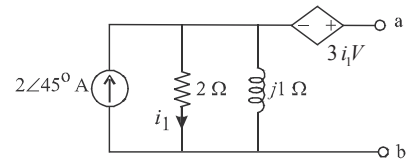
9. A linear time invariant RLC network is shown in the figure.



The state equation corresponding to the state variables $v(t)$, $i_1(t)$ and $i_2(t)$ is

- (a)
$$\begin{array}{ccccccc} \frac{dv}{dt} \neg & \neg & 0 & \frac{-1}{C} & \frac{-1}{C} & \neg & \neg \\ \frac{di_1}{dt} = \frac{1}{L_1} & \frac{-R_1}{L_1} & 0 & i_1 & + & -1 & e \\ \frac{di_2}{dt} \Downarrow & \Downarrow & \frac{1}{L_2} & 0 & \frac{-R_2}{L_2} & \Downarrow & \Downarrow \\ \equiv & \equiv & \equiv & \equiv & \equiv & \equiv & \equiv \end{array}$$
- (b)
$$\begin{array}{ccccccc} \frac{dv}{dt} \neg & \neg & 0 & \frac{1}{C} & \frac{1}{C} & \neg & \neg \\ \frac{di_1}{dt} = \frac{1}{L_1} & \frac{-R_1}{L_1} & 0 & i_1 & + & -1 & e \\ \frac{di_2}{dt} \Downarrow & \Downarrow & \frac{1}{L_2} & 0 & \frac{-R_2}{L_2} & \Downarrow & \Downarrow \\ \equiv & \equiv & \equiv & \equiv & \equiv & \equiv & \equiv \end{array}$$
- (c)
$$\begin{array}{ccccccc} \frac{dv}{dt} \neg & \neg & 0 & \frac{-1}{C} & \frac{-1}{C} & \neg & \neg \\ \frac{di_1}{dt} = \frac{1}{L_1} & \frac{R_1}{L_1} & 0 & i_1 & + & -1 & e \\ \frac{di_2}{dt} \Downarrow & \Downarrow & \frac{1}{L_2} & 0 & \frac{R_2}{L_2} & \Downarrow & \Downarrow \\ \equiv & \equiv & \equiv & \equiv & \equiv & \equiv & \equiv \end{array}$$
- (d)
$$\begin{array}{ccccccc} \frac{dv}{dt} \neg & \neg & 0 & \frac{-1}{C} & \frac{-1}{C} & \neg & \neg \\ \frac{di_1}{dt} = \frac{1}{L_1} & \frac{R_1}{L_1} & 0 & i_1 & + & -1 & e \\ \frac{di_2}{dt} \Downarrow & \Downarrow & \frac{1}{L_2} & 0 & \frac{R_2}{L_2} & \Downarrow & \Downarrow \\ \equiv & \equiv & \equiv & \equiv & \equiv & \equiv & \equiv \end{array}$$

10. The Norton equivalent admittance (in S) with respect to terminals a-b of the circuit shown in figure is

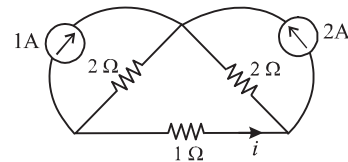


- (a) $0.2 - j 0.4$ (b) $0.1 - j 0.2$
(c) $1 - j 2$ (d) $5 + j 2.5$

11. When a unit ramp is applied as input to a linear time invariant system having transfer function $H(s) = \frac{s}{s^2 + 4s + 3}$, the steady state output is

- (a) ∞ (b) $1/3$
(c) $1/4$ (d) $1/5$

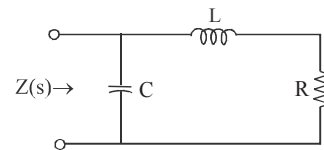
12. The current i through the 1Ω resistor shown in figure is



- (a) $-\frac{1}{3}A$ (b) $\frac{1}{5}A$
(c) $\frac{2}{5}A$ (d) $1A$

13. The driving point impedance of the network in figure is given

by $Z(s) = \frac{s+3}{2s^2 + 6s + 1}$



The values of the components are

- (a) $R = 3\Omega$, $L = 1H$ and $C = 2F$
(b) $R = 3\Omega$, $L = 2H$ and $C = 1F$
(c) $R = 3\Omega$, $L = 0.5H$ and $C = 4F$
(d) $R = 3\Omega$, $L = 4H$ and $C = 0.5F$

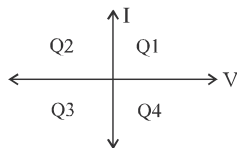
14. At room temperature, which one of the following band gap energy E_g corresponds to that of a semiconductor?

- (a) $E_g = 0eV$ (b) $E_g = 1.2eV$
(c) $E_g = 5eV$ (d) $E_g = 9eV$

15. Resistivity of an n-type Si material at a particular temperature is $0.625\Omega\text{cm}$. The electron and hole mobilities in that material at the same temperature are $\mu_n = 600\text{cm}^2/V\text{-s}$ and $\mu_p = 500\text{cm}^2/V\text{-s}$, respectively. Which one of the following best represents the donor dopant concentration N_D ?

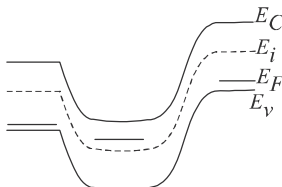
- (a) $2.5 \times 10^{13}\text{cm}^{-3}$ (b) $6.25 \times 10^{13}\text{cm}^{-3}$
(c) $6.25 \times 10^{15}\text{cm}^{-3}$ (d) $2.5 \times 10^{16}\text{cm}^{-3}$

16. The diffusion constant and mobility for electrons in a semiconductor material at a given temperature are $20 \text{ cm}^2 / \text{V-s}$, and $600 \text{ cm}^2 / \text{V-s}$, respectively. The thermal voltage V_T for a diode made of this material at the same temperature is
- (a) 125 mV (b) 32 mV
(c) 12.5 mV (d) 3.2 mV
17. A diode D_1 , under certain biasing conditions, has a forward voltage drop $V_{D1} = 0.7 \text{ V}$ and current $I_{D1} = 5.6 \text{ mA}$. Under the same external conditions, another diode D_2 whose doping levels N_A and N_D are both twice that of D_1 has the same forward voltage drop $V_{D2} = 0.7 \text{ V}$. Assuming the same ideality factor for both the diodes, I_{D2} is
- (a) 1.4 mA (b) 2.8 mA
(c) 5.6 mA (d) 11.2 mA
18. If C_d and C_s represent the depletion and diffusion capacitances of a diode, respectively, which one of the following statements is **NOT** correct?
- (a) C_d varies inversely with the depletion width.
(b) C_s varies directly with the rate of change of diode current with respect to diode voltage.
(c) C_d varies directly with the transit time.
(d) Effective junction capacitance is the parallel combination of C_s and C_d
19. The correct match between the following two columns is
- | | |
|-------------------|----------------------------|
| P. Tunnel diode | 1. Microwave amplification |
| Q. Zener diode | 2. Voltage regulation |
| R. PIN diode | 3. photo detection |
| S. Schottky diode | 4. High speed switching |
P	Q	R	S
(a) 3	4	2	1
(b) 1	3	2	4
(c) 4	2	1	3
(d) 1	2	3	4
20. The I-V characteristics of devices can be divided into quadrants as shown in figure



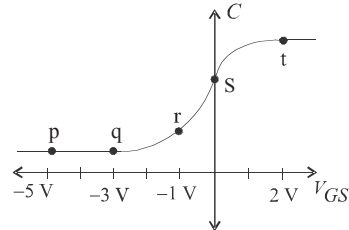
Photodiodes and solar cells are normally operated in quadrants

- (a) Q3 and Q4, respectively
(b) Q1 and Q1, respectively
(c) Q1 and Q3, respectively
(d) Q2 and Q3, respectively
21. The band structure of a BJT is shown in figure



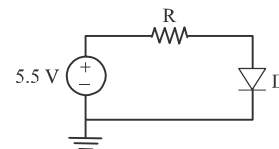
It represents

- (a) a pnp BJT biased in active mode
(b) an npn BJT biased in saturation mode
(c) an npn BJT biased in reverse active mode
(d) a pnp BJT biased in cutoff mode
22. The high frequency $C-V_{GS}$ characteristics of a MOSFET is shown in figure ($V_{DS} = 0$).



In the curve, the accumulation condition is shown by the point

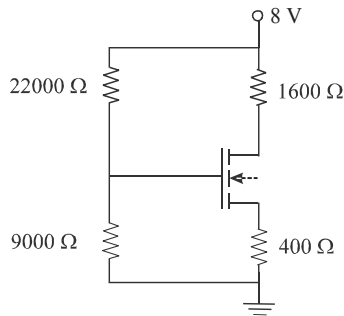
- (a) p (b) q
(c) s (d) t
23. The $C-V_{GS}$ characteristics shown in figure is of
- (a) an enhancement type PMOSFET
(b) an enhancement type NMOSFET
(c) a depletion type PMOSFET
(d) a depletion type NMOSFET
24. In circuits fabricated by n-tub process, for electrical isolation between NMOSFETs and PMOSFETs in the IC,
- (a) both p-type and n-type substrates are grounded
(b) p-type substrate is grounded and n-type substrate is connected to the most positive part of the circuit.
(c) n-type substrate is grounded and p-type substrate is connected to the most positive part of the circuit.
(d) n-type substrate is grounded and p-type substrate is connected to the most negative part of the circuit.
25. The cut-in voltage V_f and the thermal voltage V_T for the diode D in figure are 0.498 V and 2 mV, respectively.



If the value of resistor R is 20Ω , the current flowing through the diode is

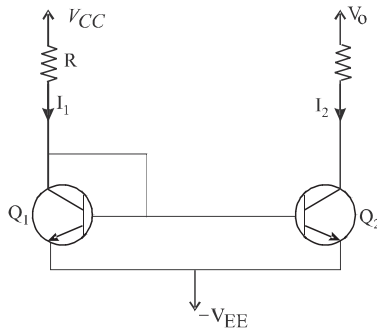
- (a) 275 mA (b) 250 mA
(c) 200 mA (d) less than 200 mA
26. Two MOSFETs M_1 and M_2 have channel widths and lengths of W, L and $2W, L/2$, and drain currents of I_{D1} and I_{D2} , respectively. Assuming that both M_1 and M_2 are ON, under the same temperature and biasing voltages, which one of the following is TRUE?
- (a) $I_{D2} = I_{D1} / 4$ (b) $I_{D2} = I_{D1} / 2$
(c) $I_{D2} = 2 I_{D1}$ (d) $I_{D2} = 4 I_{D1}$

27. The slope (in A/V) of the $I_D - V_{DS}$ load line for the circuit shown in figure is



- (a) $-1/400$ (b) $-1/1600$
(c) $-1/2000$ (d) $-1/31000$

28. In the circuit shown in figure, β is the same for both the BJTs



Neglecting early effect, $\frac{I_2}{I_1}$ is

- (a) $\frac{1+\beta}{2}$ (b) $\frac{1}{1+\beta}$
(c) $\frac{1+\beta}{2+\beta}$ (d) $\frac{\beta}{2+\beta}$

29. An n-type MOSFET and an npn BJT are biased so that $I_c = I_D = 1$ mA, $V_{GS} = 1.3$ V and $V_{BE} = 0.7$ V. Threshold voltage for the MOSFET is 0.8 V and thermal voltage at the ambient temperature is given to be 25 mV. Transconductances of the BJT and the MOSFET are

- (a) $g_{mBJT} = 40$ mA/V and $g_{mMOSFET} = 4$ mA/V
(b) $g_{mBJT} = 40$ mA/V and $g_{mMOSFET} = 2.5$ mA/V
(c) $g_{mBJT} = 80$ mA/V and $g_{mMOSFET} = 2.5$ mA/V
(d) $g_{mBJT} = 80$ mA/V and $g_{mMOSFET} = 2.5$ mA/V $g_{mBJT} = 80$ mA/V and

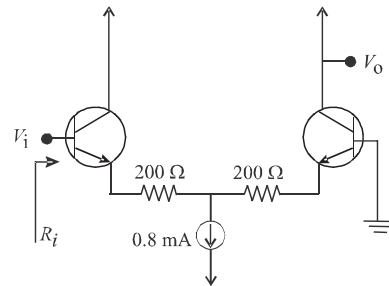
30. Adding a degeneration resistor R_E to a common emitter BJT amplifier will mainly reduce
(a) the voltage gain
(b) the input impedance
(c) the amplifier bandwidth
(d) the output impedance

31. A BJT Darlington pair has
(a) high input impedance and high β
(b) high input impedance and low β
(c) low input impedance and high β
(d) low input impedance and low β

32. The feedback scheme used in a simple opamp based non-inverting amplifier is
(a) series-series
(b) series-shunt
(c) shunt-series
(d) shunt-shunt

33. An inverting amplifier is designed for a gain of 40 dB using an opamp having open loop gain of 250000 and unity -gain frequency of 750 kHz. The bandwidth of the designed amplifier is
(a) 2.5 kHz (b) 7.5 kHz
(c) 750 kHz (d) 250 kHz

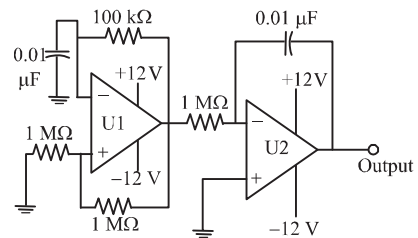
34. In the circuit shown in figure, β for both the BJTs is 99.



Assuming the thermal voltage to be 50 mV, the input resistance R_i is

- (a) 65 k Ω (b) 25 k Ω
(c) 40 k Ω (d) 65 k Ω

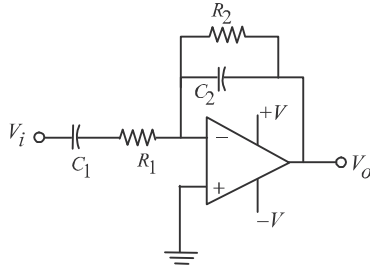
35. Assuming ideal opamps and that the opamp U2 is not saturated, the output voltage waveform in the circuit shown in figure is a



- (a) Pulse (b) sine wave
(c) triangular wave (d) square wave

36. For a class-A power amplifier, supply dc voltage is ± 12 V, the quiescent collector current is 72 mA and the load resistance is 100 Ω . If the output voltage across the load is 12 V peak-to-peak, the efficiency of the amplifier is (neglect the loss occurring in the bias resistors)
(a) 10.4% (b) 20.8%
(c) 25% (d) 33.3%

37. The gain at the centre-frequency for the bandpass filter shown in figure is



- (a) $-\frac{\sqrt{R_1 C_1}}{\sqrt{R_2 C_2}}$ (b) $-\frac{\sqrt{R_2 C_2}}{\sqrt{R_1 C_1}}$
 (c) $-\frac{R_1}{R_2} + \frac{C_2}{C_1}$ (d) $-\frac{1}{\frac{R_1}{R_2} + \frac{C_2}{C_1}}$

38. The specifications given for a TTL logic family gate are as follows:

$I_{OH} = 0400 \text{ pA}$, $I_{OL} = 8 \text{ mA}$, $I_{IH} = 20 \text{ pA}$ and $I_{IL} = -0.36 \text{ mA}$. The fan-out of the gate is

- (a) 10 (b) 18
 (c) 20 (d) 22

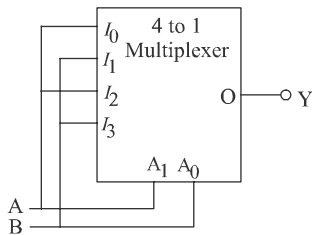
39. In the logic equation

$$A(A + \overline{B}\overline{C} + C) + \overline{B}(\overline{C} + \overline{A} + BC)(A + \overline{B}C + A\overline{C}) = 1,$$

if $C = \overline{A}$ then

- (a) $A + B = 1$ (b) $\overline{A} + B = 1$
 (c) $A + \overline{B} = 1$ (d) $A = 1$

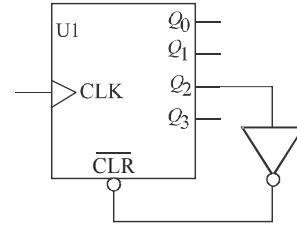
40. A gate having two inputs (A, B) and one output (Y) is implemented using a 4-to-1 multiplexer as shown in figure. A_1 (MSB) and A_0 are the control bits and $I_0 - I_3$ are the inputs to the multiplexer.



The gate is

- (a) NAND (b) NOR
 (c) XOR (d) OR

41. In figure, U1 is a 4-bit binary synchronous counter with synchronous clear. Q_0 is the LSB and Q_3 is the MSB of the output



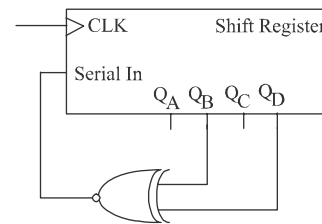
The circuit shown in figure represents a

- (a) mod 2 counter (b) mod 3 counter
 (c) mod 4 counter (d) mod 5 counter

42. An increase in the value of the hold capacitor in a sample-and-hold circuit results in

- (a) decrease in the acquisition time and decrease in the droop rate
 (b) decrease in the acquisition time and increase in the droop rate
 (c) increase in the acquisition time and increase in the droop rate
 (d) increase in the acquisition time and decrease in the droop rate

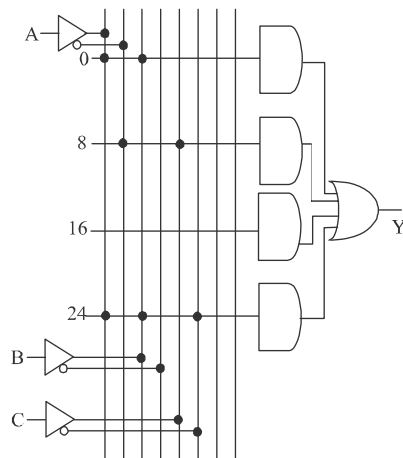
43. A 4-bit serial-in-parallel-out shift register is used with a feedback as shown in figure. The shifting sequence is $Q_A \rightarrow Q_B \rightarrow Q_C \rightarrow Q_D$.



If the output is 0000 initially, the output repeats after

- (a) 4 clock cycles (b) 6 clock cycles
 (c) 15 clock cycles (d) 16 clock cycles

44. Figure shows a section of a Programmable Logic Device (PLD).



The Boolean expression implemented in the PLD is

- (a) $AC + AB + \bar{A}B\bar{C}$
 (b) $A\bar{C} + \bar{A}B + AB\bar{C}$
 (c) $AB + \bar{A}C + A\bar{B}C$
 (d) $AB + \bar{A}C + AB\bar{C}$

45. For an 8-bit digital-to-analog converter having reference voltage of 8 V, the least significant 4 bits of the input are grounded and the most significant 4 bits are driven by 4 bit data from a binary counter. The maximum obtainable peak-to-peak amplitude of a waveform at the output of the digital-to-analog converter is

- (a) 4V (b) 6V
 (c) 7.2 V (d) 7.2 V

46. Which one of the following statements about the 8085 is TRUE?

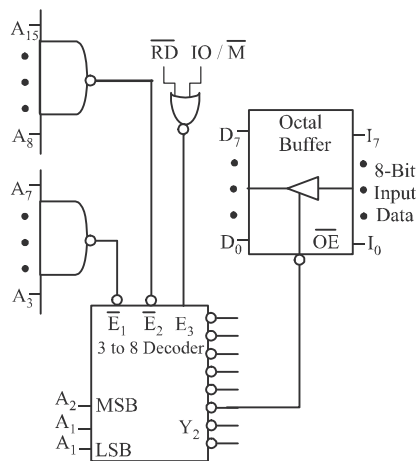
- (a) Only accumulator can be loaded with an 8-bit number in a single instruction.
 (b) The processor can be interrupted even after it executes HLT instruction.
 (c) When HOLD input is activated, the processor can execute register-to-register instructions.
 (d) The program and data memories are separate.

47. The contents of the HL register pair after the execution of the following program on the 8085 are

```
LXI H, 2095H
LXI B, 8FBFH
PUSH B
XTHL
POPH
HLT
```

- (a) 2095 H (b) 20BFH
 (c) 8F95H (d) 8FBFH

48. The figure shows an interfacing circuit for the 8085 microprocessor to read an 8-bit data from an external device.



The appropriate instruction for reading the data is

- (a) MVI A, FAH (b) IN FAH
 (c) IN FFAH (d) LDA FFAH

49. When the 8085 receives an interrupt on the INTR pin,

- (a) the program is directly transferred to a fixed call location
 (b) 8085 waits till an interrupt acknowledgement is received and transfers program to a fixed call location
 (c) the call location is determined by an external device
 (d) the program is transferred to a call location indicated by HL register pair,

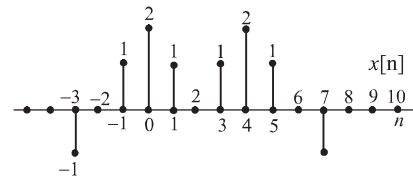
50. An input $x[n]$ with length 3 is applied to a linear time invariant system having an impulse response $h[n]$ of length 5, and $Y(\omega)$ is the DTFT of the output $y[n]$ of the system. If $|h[n]| \leq L$ and $|x[n]| \leq B$ for all n , the maximum value of $y(0)$ can be $y[n]$

- (a) 15 LB (b) 12 LB
 (c) 8 LB (d) 7 LB

51. The two-sided Laplace transform of $x(t) = e^{-3t} u(t) + e^{2t} u(-t)$ is

- (a) $X(s) = \frac{-5}{s^2 + s - 6}, -3 < \sigma < 2$
 (b) $X(s) = \frac{-5}{s^2 + s - 6}, 2 < \sigma < 3$
 (c) $X(s) = \frac{-5}{s^2 + s - 6}, -3 < \sigma < -2$
 (d) $X(s) = \frac{-5}{s^2 + s - 6}, -2 < \sigma < 3$

52. For the signal $x[n]$ shown in figure $x[n] = 0$ for $n < -3$ and $n > 7$



If $X(\omega)$ is the Fourier transform of $x[n]$, which one of the following is TRUE?

- (a) $X(0) = 5$
 (b) $\int_{-\pi}^{\pi} X(\omega) d\omega = 2\pi$
 (c) The phase $\angle X(\omega) = -2\omega$
 (d) $X(\omega) = X(-\omega)$

53. For a time invariant system, the different combinations of the input $x_i[n]$ and corresponding output $y_i[0]$ are given below. The arrow indicates the position of $x_i[0]$ and $y_i[0]$

$$x_1[n] = \{\dots, 0, 3, 2, 0, \dots\}$$

$$\text{and } y_1[n] = \{\dots, 0, 0, 2, 3, 0, \dots\}$$

$$\text{and } y_2[n] = \{\dots, 0, 0, 2, 2, 4, 0, \dots\}$$

$$x_3[n] = \{\dots, 0, 3, 0, \dots\}$$

$$\text{and } y_3[n] = \{ \dots, 0, 0, 3, 6, 0, \dots \}$$

$$x_4[n] = \{ \dots, 0, 0, 0, 1, 0, \dots \}$$

$$\text{and } y_4[n] = \{ \dots, 0, 3, 2, 0, 0, \dots \}$$

The impulse response $h[n]$ of the system is

$$(a) \{ \dots, 0, 0, 2, 1, -4, 0, \dots \}$$

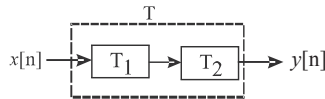
$$(b) \{ \dots, 0, 1, 1, 2, 0, \dots \}$$

$$(c) \{ \dots, 0, 3, 2, 0, 0, 0, \dots \}$$

$$(d) \{ \dots, 0, 1, 2, 0, \dots \}$$

54. Two system T_1 and T_2 are cascaded to get the system T as shown in figure

Which one of the following statements is true?

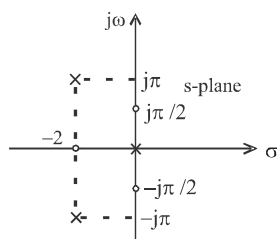


- (a) If both T_1 and T_2 are linear then T is **NOT** necessarily linear.
 (b) If both T_1 and T_2 are time invariant then T is **NOT** necessarily time invariant.
 (c) If both T_1 and T_2 are non-linear T is **NOT** necessarily non-linear.
 (d) If both T_1 and T_2 are causal then T is **NOT** necessarily causal.

55. If $x[n] = \frac{2}{\pi} \sin \frac{2n\pi}{\pi n}$, $n = 0$, the energy of $x[n]$ is

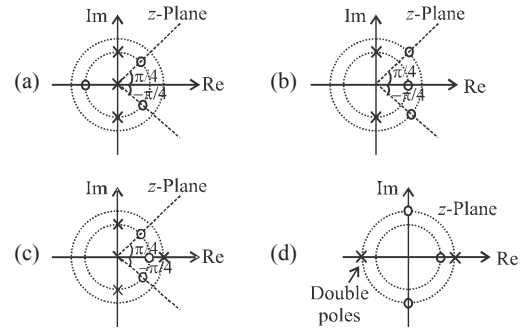
- (a) $\frac{2}{\pi}$ (b) $\frac{1}{\pi}$
 (c) $\frac{1}{2\pi}$ (d) $\frac{3}{\pi}$

56. The pole-zero plot of the transfer function ($H_a(s)$) of a linear time invariant system in s-plane is shown in figure. The corresponding impulse response $h_a(t)$ is sampled at 2 Hz to get the discrete-time impulse response sequence $h[n]$



If the right half of the s-plane is mapped into the outside of the unit circle, which one of the following shows the equivalent pole-zero plot of $H(z)$ in the z-plane

the concentric circles are $|z| = \frac{1}{e}$ and $|z| = 1$?



57. The z-transform $X(z)$ of a sequence $x[n]$ is given by

$$X(z) = \frac{z^{20}}{z - \frac{1}{2} (z - 2)(z + 3)}$$

If $X(z)$ converges for $|z| = 1$ then $x[-18]$ is

- (a) $-\frac{1}{9}$ (b) $-\frac{2}{21}$
 (c) $-\frac{1}{10}$ (d) $-\frac{2}{27}$

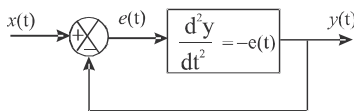
58. The z-transform $X(z)$ of a real and right-sided sequence $x[n]$ has exactly two poles and one of them is at $z = e^{j\pi/2}$ and there are two zeroes at the origin. If $X(1) = 1$, which one of the following is true?

- (a) $X(z) = \frac{2z^2}{(z-1)^2 + 2}$, ROC is $\frac{1}{2} < |z| < 1$
 (b) $X(z) = \frac{2z^2}{z^2 + 1}$, ROC is $|z| > \frac{1}{2}$
 (c) $X(z) = \frac{2z^2}{(z-1)^2 + 2}$, ROC is $|z| > 1$
 (d) $X(z) = \frac{2z^2}{z^2 + 1}$, ROC is $|z| > 1$

59. The impulse response $h[n]$ of a linear time invariant system is real. The transfer function $H(z)$ of the system has only one pole and it is at $z = \frac{4}{3}$. The zeros of $H(z)$ are non-real and located at $z = \frac{3}{4}$. The system is

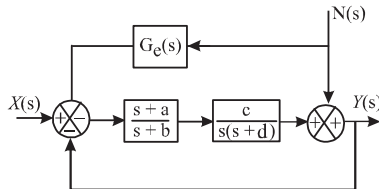
- (a) stable and causal
 (b) unstable and anti-causal
 (c) unstable and causal
 (d) stable and anti-causal

60. A signal $x(t)$ is band-limited to W Hz, and $y(t) = x^3(t) + x(t) + 1$. The Nyquist sampling frequency of $y(t)$ is
 (a) $3W$ (b) $6W$
 (c) $12W$ (d) $27W$
61. Suppose $X(k)$ is the 6-point Discrete Fourier Transform (DFT) of $x[n] = \{4, 3, 2, 1, 0, 0\}$, and $y(k) = W_6^{4k} X[k]$, where $y[k]$ is the 6-point DFT of $y[n]$ and $W_6 = e^{-j\frac{2\pi}{6}}$. Which one of the following represents $y[n]$?
 (a) $y[n] = \{0, 3, 2, 1, 0, 4\}$
 (b) $y[n] = \{2, 1, 0, 0, 4, 3\}$
 (c) $y[n] = \{0, 0, 0, 0, 4, 3, 2, 1\}$
 (d) $y[n] = \{3, 2, 1, 0, 0, 4\}$
62. A signal $x(t) = \cos(10t) \cos(100t)$ is passed through a system whose impulse response is $H(\omega) = \exp(-j100 - j2(\omega - 100))$. If $y(t)$ is the system output, then
 (a) $y(t) = \cos 10t - \frac{1}{2} \cos(100(t-1))$
 (b) $y(t) = \cos(10(t-1)) \cos 100t - \frac{1}{2}$
 (c) $y(t) = \cos(10(t-2)) \cos(100(t-1))$
 (d) $y(t) = \cos(10(t-1)) \cos(100(t-2))$
63. For the system shown in figure $e(t)$ is the error between input $x(t)$ and output $y(t)$



If $x(t) = t u(t)$ and all initial conditions are zero, then $e(t)$ will be

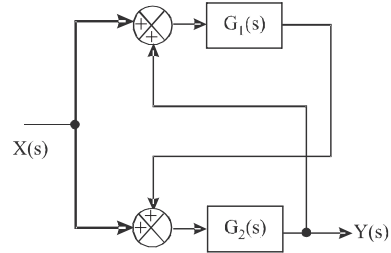
- (a) $\sin t$ (b) $\cos t$
 (c) $-\cos t$ (d) $-\sin t$
64. For a linear time invariant system shown in figure, $X(s)$ is the input and $Y(s)$ is



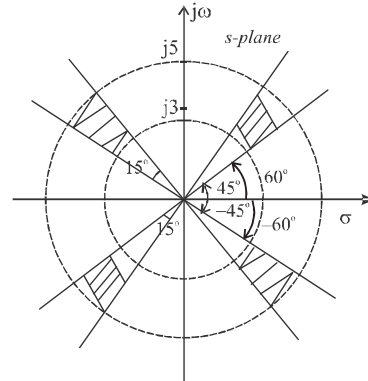
In order to nullify the effect of noise $N(s)$, the gain of the feed-forward path $G_e(s)$ is

- (a) $\frac{s(s+a)(s+d)}{c(s+b)}$ (b) $\frac{c(s+b)}{s(s+a)(s+d)}$
 (c) $\frac{s(s+b)(s+d)}{c(s+a)}$ (d) $\frac{c(s+a)}{s(s+b)(s+d)}$

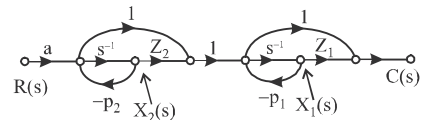
65. The transfer function $\frac{Y(s)}{X(s)}$ of the linear time invariant system shown in figure



- (a) $\frac{G_1(s)(G_2(s)+1)}{1-G_1(s)G_2(s)}$ (b) $\frac{G_2(s)(G_1(s)+1)}{1-G_1(s)G_2(s)}$
 (c) $\frac{G_1(s)(G_2(s)+1)}{1-G_1(s)G_2(s)}$ (d) $\frac{G_2(s)(G_1(s)+1)}{1+G_1(s)G_2(s)}$
66. The characteristic polynomial of a feedback control system is $s^3 + Ks^2 + 9s + 18$. When the system is marginally stable, the frequency of the sustained oscillation (in rad/s) is
 (a) 1 (b) $\sqrt{2}$
 (c) $\sqrt{3}$ (d) 3
67. A unity feedback system has the open-loop transfer function $G(s) = \frac{\omega_n^2}{s(s+2\zeta\omega_n)}$. If the closed-loop poles lie in the shaded region of the s -plane as shown in figure, which one of the following is true?

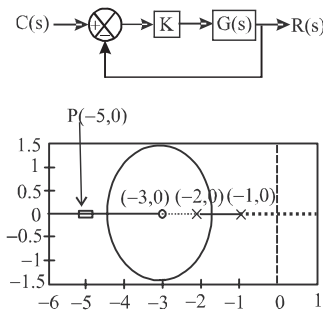


- (a) $0.5 \leq \zeta \leq 0.707, 3 \text{ rad/s} \leq \omega_n \leq 5 \text{ rad/s}$
 (b) $0.707 \leq \zeta \leq 0.867, \omega_n \leq 5 \text{ rad/s}$
 (c) $0.5 \leq |\zeta| \leq 0.707, 3 \text{ rad/s} \leq \omega_n \leq 5 \text{ rad/s}$
 (d) $0.707 \leq |\zeta| \leq 0.867, \omega_n \leq 5 \text{ rad/s}$
68. The state equation for the state diagram shown in figure is



- (a) $\neg x_1 \neg \neg P_1 \quad z_2 \neg p_2 \neg x_1 \neg \neg a \neg r(t)$
 $\equiv x_2 \downarrow \equiv 0 \quad \neg p_2 \downarrow \equiv x_2 \downarrow \equiv a \downarrow$
- (b) $\neg x_1 \neg \neg P_1 \quad z_2 \neg p_2 \neg x_1 \neg \neg a \neg r(t)$
 $\equiv x_2 \downarrow \equiv 0 \quad \neg p_2 \downarrow \equiv x_2 \downarrow \equiv 0 \downarrow$
- (c) $\neg x_1 \neg \neg P_1 \quad z_2 \neg p_2 \neg x_1 \neg \neg a \neg r(t)$
 $\equiv x_2 \downarrow \equiv p_2 \quad z_1 \neg p_1 \downarrow \equiv x_2 \downarrow \equiv a \downarrow$
- (d) $\neg x_1 \neg \neg P_1 \quad z_2 \neg p_2 \neg x_1 \neg \neg a \neg r(t)$
 $\equiv x_2 \downarrow \equiv p_2 \quad z_1 \neg p_1 \downarrow \equiv x_2 \downarrow \equiv 0 \downarrow$

69. A unity feedback system is shown in figure. The root-locus of its characteristic equation is shown in figure



If $P(-5, 0)$ is a point on the root-locus, the variable parameter K of the system at P is

- (a) 2 (b) 4
 (c) 6 (d) 8
70. For a unity feedback system shown in figure Q. 69, the root-locus of the characteristic equation is shown in figure Q. 70. If the variable parameter $K = 2$, the closed-loop transfer function of the system is
- (a) $\frac{s+3}{s^2+3s+2}$ (b) $\frac{2(s+3)}{s^2+5s+8}$
 (c) $\frac{2(s+3)}{s^2+3s+2}$ (d) $\frac{s+3}{s^2+5s+8}$
71. The open-loop transfer function of a system is given by $G(s)H(s) = \frac{100(s+100)}{s(s+10)}$. In the straight-line approximation of the Bode plot, $|G(j\omega)H(j\omega)|$ and $\angle G(j\omega)H(j\omega)$ at $\omega = 100$ rad/s are
- (a) 0 dB and $-\frac{3\pi}{4}$ rad (b) 0 dB and $\frac{\pi}{4}$ rad
 (c) 0 dB and $-\frac{3\pi}{4}$ rad (d) 20 dB and $\frac{\pi}{4}$ rad
72. A linear time invariant system with input $u(t)$ and output $y(t)$ is described by the state-space representation as given below.

$$\dot{x}_1(t) = x_2(t)$$

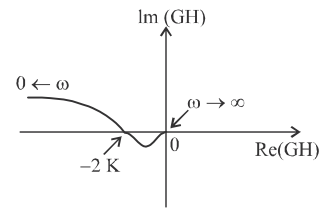
$$\dot{x}_2(t) = x_1(t) + x_2(t) + u(t)$$

and $y(t) = x_1(t) + 3x_2(t)$

The transfer function of the system is

- (a) $\frac{s+3}{s^2-s-1}$ (b) $\frac{s+3}{s^2+s+1}$
 (c) $\frac{3s+1}{s^2+s+1}$ (d) $\frac{3s+1}{s^2-s-1}$

73. A unity feedback closed-loop system has a plant $G(s) = \frac{1}{s^2}$ and a PD controller $G_c(s)$ in the forward path. if $G_c(s) = T_p(1 + T_D s)$ where T_p and T_D are positive adjustable parameters, which one of the following statements is NOT true?
- (a) The system is always stable.
 (b) The system may have damped oscillation for a unit-step input.
 (c) The system amplifies the noise.
 (d) The system has zero steady-state error for a unit-step input.
74. Suppose the Nyquist plot of the loop transfer function $G(j\omega)H(j\omega)$ for $\omega = 0$ and $\omega = \infty$ for a single-loop feedback control system is shown in figure. The gain K appears as a multiplying factor in $G(s)H(s)$. One pole of $G(s)H(s)$ lies in the right half of s-plane and no pole is on the $j\omega$ axis.



Which one of the following statements is true in the case of closed-loop stability?

- (a) The closed-loop system is stable for $0.25 < K < 0.5$
 (b) The closed-loop system is stable for $K > 0.5$
 (c) The closed-loop system is unstable for all values of K
 (d) The closed-loop system is stable for $K = 0.25$
75. Consider an amplitude modulated (AM) wave $C_m(t) = (A_c + A_m \cos \omega_m t) \cos \omega_c t$. If P_s denotes the power in any one of the side frequencies and P_T denotes the total power of the AM signal for $A_c = 2A_m$ which one of the following is true? $C_m(t) = (A_c + A_m \cos \omega_m t) \cos \omega_c t$
- (a) $P_T = 3P_s$ (b) $P_T = 6P_s$
 (c) $P_T = 9P_s$ (d) $P_T = 18P_s$
76. In a superheterodyne receiver, if the intermediate frequency is 10.7 MHz and the carrier frequency is 89.6 MHz, the image frequency is
- (a) 78.9 MHz (b) 100.3 MHz
 (c) 111 MHz (d) 121 MHz
77. For the frequency modulated signal

$$v(t) = \cos \left[2\pi f_c t + k \int_{-\infty}^t m(\tau) d\tau \right], \text{ if } m(t) \text{ has a probability density function}$$

$f_m(m) = \frac{1}{2\sqrt{2\pi}} e^{-\frac{m^2}{8}}$, the rms frequency deviation is

- (a) k (b) $2k$
(c) $\frac{k}{2\pi}$ (d) $\frac{k}{\pi}$

78. A PCM system uses a uniform quantizer which has a range $-V$ to $+V$ and it is followed by a 7 bit binary encoder. A zero mean signal applied to the quantizer extends over its entire range and has uniform probability density. The ratio of the signal power to the quantization noise power at the output of the quantizer is (Take $\log_{10} 2 \approx 0.3$)

- (a) 14 dB (b) 28 dB
(c) 42 dB (d) 56 dB

79. A source generates one of the five symbols¹, s^2 , s^3 , s^4 and s^5 once in every $\frac{1}{60}$ second. The symbols are assumed to be independent and occur with probabilities $\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{8}$ and $\frac{1}{8}$.

The average information rate of the source in bits/second is

- (a) 100 (b) 125
(c) 136 (d) 150

80. A source has 256 symbols which are equiprobable and their successive transmissions are independent. If an AWGN channel having a bandwidth of 4 kHz and SNR of 31 is used for transmission of symbols, the maximum rate (in symbols/s) at which the transmission can be made with an arbitrary low probability of error is

- (a) 1000 (b) 1500
(c) 2000 (d) 2500

81. A communication system operates in an AWGN channel and employs BPSK modulation. If $\frac{E_b}{N_0} = 4$, signal energy per bit, N_0 : noise power spectral density and given that $\text{erf}(2) = 0.99532$, the average BER is

- (a) 2.34×10^{-1} (b) 2.34×10^{-1}
(c) 4.68×10^{-1} (d) 4.68×10^{-1}

82. A matched filter having a frequency response

$$H(f) = \frac{1 - e^{-j2\pi f T}}{j2\pi f}$$
 matches to

- (a) $s(t) = \begin{cases} 1, & 0 \leq t \leq T \\ 0, & \text{otherwise} \end{cases}$
(b) $s(t) = \begin{cases} -1, & 0 \leq t \leq T \\ 0, & \text{otherwise} \end{cases}$
(c) $s(t) = \begin{cases} 1 - \frac{t}{T}, & 0 \leq t \leq T \\ 0, & \text{otherwise} \end{cases}$
(d) $s(t) = \begin{cases} -1 + \frac{t}{T}, & 0 \leq t \leq T \\ 0, & \text{otherwise} \end{cases}$

83. An amplitude modulated signal

$s(t) = A_c [1 + km(t)] \cos 2\pi f_c t$ (message signal $m(t)$ has power P and constant K determines the modulation index) is sent through an AWGN channel and detected using an envelope detector. If the average carrier power is large compared to the noise power and any DC component present at the envelope detector output is removed, the figure of merit of the detector is

- (a) $\frac{k^2 P}{1 + k^2 P}$ (b) $\frac{P}{1 + k^2 P}$
(c) $\frac{2P}{A_c^2 + 2k^2 P}$ (d) $\frac{P}{k^2 + P}$

84. Which one of the following statements is not true?

- (a) A frequency modulated signal is produced when a modulating signal $m(t)$ is integrated and applied to a phase modulator.
(b) For a sinusoidally modulated FM carrier, it is possible that for particular values of the modulation index β , all the power lies in the side frequencies and no power in the carrier.
(c) When carrier to noise ratio is high, an increase in the transmission bandwidth decreases the figure of merit of an FM system.
(d) A phase modulated signal is produced when a modulating signal $m(t)$ is differentiated and applied to a frequency modulator.

85. If E_b , T_b and f_c respectively denote bit energy, bit duration and the carrier frequency, the signal

$$u_m(t) = \sqrt{\frac{2E_b}{T_b}} \left[\cos(2\pi f_c t) \cos \frac{m\pi}{T_b} t - \sin(2\pi f_c t) \sin \frac{m\pi}{T_b} t \right]$$

$m \in [0, 1]$ and $0 \leq t \leq T_b$ represents a

- (a) BPSK modulated signal
(b) QPSK modulated signal
(c) DPSK modulated signal
(d) BFSK modulated signal

86. Which one of the following statements is not true?

- (a) TDMA systems have high synchronization overhead.
(b) Power control is used to combat the near-far problem in CDMA implementations.
(c) IS-95 is a TDMA digital cellular standard.
(d) The modulation scheme used in GSM is GMSK.

87. There are two fair coins

$P(\text{Head}) = P(\text{Tail}) = \frac{1}{2}$ and a third biased coin where

$P(\text{Head}) = \frac{1}{4}$ and $P(\text{Tail}) = \frac{3}{4}$. One coin is picked at random and tossed once and a Head is obtained. The probability that the coin tossed is one of the fair coins is

- (a) $\frac{5}{6}$ (b) $\frac{4}{5}$
(c) $\frac{3}{4}$ (d) $\frac{2}{3}$

88. Which one of the following can not be the auto-correlation function $R_x(\tau)$ of a real wide sense stationary random process $X(t)$?

- (a) $R_x(\tau) = \begin{cases} 1, & |\tau| \leq 1 \\ 0, & \text{otherwise} \end{cases}$
 (b) $R_x(\tau) = \frac{\sin \tau}{2\tau}$
 (c) $R_x(\tau) = 1 - \sin^2 \tau$
 (d) $R_x(\tau) = \begin{cases} 1 - |\tau|, & |\tau| \leq 1 \\ 0, & \text{otherwise} \end{cases}$

89. If $\vec{F}(\rho, \phi, z) = \rho \hat{a}_\rho + \rho \sin^2 \phi \hat{a}_\phi - z \hat{a}_z$, which one of the following is TRUE?

- (a) $\vec{F}|_{\phi=\frac{\pi}{4}} = \vec{F}|_{\phi=0}$ (b) $\vec{F}|_{\phi=0} > \vec{F}|_{\phi=\frac{\pi}{2}}$
 (c) $\vec{F}|_{\phi=0} > \vec{F}|_{\phi=\frac{\pi}{2}}$ (d) $\vec{F}|_{\phi=\frac{\pi}{4}} = \vec{F}|_{\phi=0}$

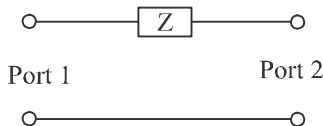
90. A plane electromagnetic wave with magnetic field $\vec{H}_i = \cos(10^8 t - \beta z) \hat{a}_y$ travels in air for $z \geq 0$ and is incident normally on a lossless non-magnetic dielectric medium of relative permittivity 4 which occupies the region $z \geq 0$. Which one of the following is the expression for the reflected electric field (in mV/m)? Given $\eta_0 = 120 \pi \Omega$ is the intrinsic impedance

- (a) $\vec{E}_r = -40\pi \cos(10^8 t - 3z) \hat{a}_x$
 (b) $\vec{E}_r = -40\pi \cos(10^8 t + \frac{1}{3}z) \hat{a}_x$
 (c) $\vec{E}_r = -80\pi \cos(10^8 t - 3z) \hat{a}_x$
 (d) $\vec{E}_r = 80\pi \cos(10^8 t + \frac{1}{3}z) \hat{a}_x$

91. When a lossless transmission line of length $\lambda/8$ is short-circuited at one end, the input impedance seen at the other end is $j50 \Omega$. If the short-circuit is now replaced by a load resistance of 75Ω , the magnitude of the reflection coefficient is
 (a) 1/5 (b) 2/5
 (c) 3/5 (d) 4/5

92. Two rectangular waveguides, one air-filled with internal dimensions $2 \text{ cm} \times 1 \text{ cm}$ and the other dielectric-filled with internal dimensions $1 \text{ cm} \times 0.5 \text{ cm}$, have the same cutoff frequency for the dominant mode. The relative permittivity of the dielectric material is
 (a) 2 (b) 4
 (c) 6 (d) 8

93. For the circuit shown in figure, which one of the following is true? (Assume characteristic impedance Z_0 for the ports)



- (a) $S_{12} = 1 + S_{11}$ (b) $S_{12} = 1 - S_{11}$
 (c) $S_{12} = 1 - S_{11}$ (d) $S_{22} = 1 + S_{21}$

94. Consider an air-filled rectangular waveguide operating in the dominant TE_{10} mode at a frequency f . For this waveguide, λ_g is the guide wavelength and λ_{c10} is the cutoff wavelength corresponding to the dominant mode. If f is so chosen that only dominant TE_{10} mode propagates, which one of the following is true?

- (a) $\frac{1}{f} = \sqrt{\epsilon_0 \mu_0} \frac{\lambda_g \lambda_{c10}}{\sqrt{\lambda_g^2 + \lambda_{c10}^2}}$
 (b) $f = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \frac{\lambda_g \lambda_{c10}}{\sqrt{\lambda_g^2 + \lambda_{c10}^2}}$
 (c) $f = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \frac{\lambda_g \lambda_{c10}}{\sqrt{\lambda_{c10}^2 - \lambda_g^2}}$
 (d) $f = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \frac{\lambda_g \lambda_{c10}}{\sqrt{\lambda_{c10}^2 - \lambda_g^2}}$

95. An electromagnetic wave having frequency f_0 gets attenuated by a factor of e^{-2} after propagating a distance d in a good conductor. If the signal frequency is now reduced to $0.5 f_0$, after traveling the same distance d in the same conductor, the signal will get attenuated by a factor of

- (a) e^{-4} (b) $e^{-2\sqrt{2}}$
 (c) $e^{-\sqrt{2}}$ (d) e^{-1}

96. If the amplitude of the time harmonic current distribution on a thin centre-fed short z-directed dipole antenna of length l ($l \ll \lambda$) is given by

$I(z) = I_0 \left(1 - \frac{2|z|}{l}\right)$, which one of the following represents radiation resistance of the antenna?

- (a) $320 \pi^2 \frac{1}{\lambda}$ (b) $80 \pi^2 \frac{1}{\lambda}$
 (c) $40 \pi^2 \frac{1}{\lambda}$ (d) $20 \pi^2 \frac{1}{\lambda}$

97. An antenna having a gain of 10 dB radiates 1.5 W power in free space. The electric field density ($|\vec{E}|$) at a distance of 1 km from

the antenna is given by Given the intrinsic impedance of free space, $\eta_0 = 120 \pi \Omega$

- (a) $15\sqrt{2} \text{ mV/m}$ (b) 30 mV/m
 (c) 60 mV/m (d) 90 V/m

98. The cladding material of a step index fiber has a relative permittivity of 2.4375. Assuming both core and cladding materials to be non-magnetic, in order to have a numerical aperture of 0.25, the refractive index of the core should be

- (a) 5 (b) 2.5
 (c) $\sqrt{3.5}$ (d) $\sqrt{2.5}$

99. Given $\vec{A} = yz\hat{a}_x + xy\hat{a}_y + xz\hat{a}_z$, $\left| \vec{A} \right|$ at the point P (0, 1, 2) is
- (a) 0 (b) $\sqrt{2}$
 (c) $\sqrt{3}$ (d) $\sqrt{5}$
100. With symbols having their usual meanings, which one of the following relationship is not correct?

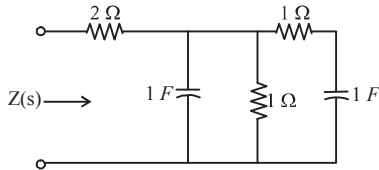
- (a) $\oint_C \vec{E} \cdot d\vec{l} = - \frac{\partial}{\partial t} \int_S \vec{H} \cdot d\vec{s}$
 (b) $\oint_C \vec{H} \cdot d\vec{l} = I + \frac{\partial}{\partial t} \int_S \vec{D} \cdot d\vec{s}$
 (c) $\oint_C \vec{B} \cdot d\vec{s} = 0$
 (d) $\oint_C \vec{D} \cdot d\vec{s} = Q$

ANSWER KEYS

1. (a)	2. (b)	3. (c)	4. (a)	5. (c)	6. (a)	7. (b)	8. (a)	9. (b)	10. (a)
11. (b)	12. (c)	13. (a)	14. (b)	15. (c)	16. (c)	17. (d)	18. (c)	19. (d)	20. (c)
21. (a)	22. (c)	23. (b)	24. (a)	25. (b)	26. (d)	27. (c)	28. (d)	29. (a)	30. (c)
31. (a)	32. (d)	33. (b)	34. (c)	35. (d)	36. (a)	37. (d)	38. (c)	39. (c)	40. (d)
41. (c)	42. (a)	43. (b)	44. (d)	45. (d)	46. (b)	47. (a)	48. (d)	49. (b)	50. (c)
51. (a)	52. (b)	53. (c)	54. (c)	55. (a)	56. (d)	57. (b)	58. (b)	59. (c)	60. (b)
61. (a)	62. (c)	63. (d)	64. (a)	65. (c)	66. (d)	67. (c)	68. (a)	69. (d)	70. (a)
71. (c)	72. (d)	73. (d)	74. (a)	75. (d)	76. (c)	77. (d)	78. (c)	79. (b)	80. (c)
81. (d)	82. (b)	83. (a)	84. (a)	85. (c)	86. (d)	87. (c)	88. (b)	89. (a)	90. (d)
91. (a)	92. (b)	93. (d)	94. (b)	95. (b)	96. (d)	97. (a)	98. (b)	99. (b)	100. (a)

TEST PAPER 6

1. For the driving point impedance function, $Z(s) = \frac{as^2 + 7s + 3}{s^2 + 3s + b}$, the circuit realization is shown below. The values of 'a' and 'b' respectively are



- (a) 4 and 5 (b) 2 and 5
(c) 2 and 1 (d) 2 and 3
2. Consider the following statements:
The A to D converter used in a digital instrument could be
1. Successive approximation converter type.
 2. Flash converter type.
 3. Dual slope converter type.
- The correct sequence in the increasing order of the conversion time taken by these types is
- (a) 1, 2 and 3 (b) 2, 1 and 3
(c) 1, 3 and 2 (d) 2, 3 and 1
3. For photoconductors with equal electron and hole mobilities and perfect ohmic contacts at the ends, an increase in intensity of optical illumination results in
- (a) a change in open circuit voltage
(b) a change in short circuit current
(c) decrease in resistance
(d) increase in resistance
4. Consider the following statements in connection with two-position controller:
1. If the controller has a 4% neutral zone, its positive error band will be 2% and negative error band will be 8%
 2. The neutral zone is also known as dead band
 3. The controller action of a two-position controller is very similar to that of a pure on-off controller.
 4. Air-conditioning system works essentially on a two-position control basis.
5. For the following driving point impedance functions, which of the following statements is true?

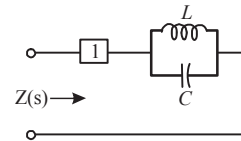
$$Z_1(s) = \frac{s+2}{s^2+3s+5}$$

$$Z_2(s) = \frac{s+2}{s^2+5}$$

$$Z_3(s) = \frac{s+3}{s^2+2s+1}$$

$$Z_4(s) = \frac{(s+2)(s+4)}{(s+1)(s+3)}$$

- (a) Z_1 is not positive real (b) Z_2 is positive real
(c) Z_3 is positive real (d) Z_4 is positive real
6. A piezoelectric crystal has a thickness of 2.5 mm and a voltage sensitivity of 0.05 Vm/N. The piezoelectric crystal is subjected to an external pressure of $1.6 \times 10^6 \text{ N/m}^2$, then the corresponding output voltage is
- (a) 200 volts
(b) 3.2×10^9 volts/m of thickness
(c) $0.07 \times 10^{-9} \text{ V/(m}^3/\text{New)}$
(d) 200 m volts
7. A reactance network in the Foster's I form has poles at $\omega = 0$ (zero) and $\omega = \infty$. The element in box-1 in the below network is



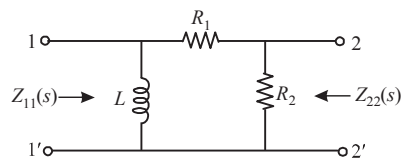
- (a) a capacitor (b) an inductor
(c) a parallel LC circuit (d) A series LC circuit
8. The measurement of Hall coefficient of a semiconductor with one type of charge carrier gives the information about
- (a) sign of charge carrier
(b) density of charge carrier
(c) both sign and density of charge carrier
(d) mass of the charge carrier
9. Consider the following statements with reference of the phase plane:
1. They are general and applicable to a system of any order.
 2. Steady state accuracy and existence of limit cycle can be predicted
 3. Amplitude and frequency of limit cycle if exists can be evaluated
 4. Can be applied to discontinuous time system.
- Which of the above statements are correct?
- (a) 1, 2, 3 and 4 (b) 2 and 3 only
(c) 3 and 4 only (d) 2, 3 and 4 only

10. Consider the following units for the measurement of pressure directly:

1. Rolta meter	2. Bourdon tube
3. Planti meter	4. Vanes

Of these, the pressure can be measured by

- (a) 1 and 2 only (b) 3 and 4 only
(c) 2 only (d) 1, 2, 3 and 4
11. For the circuit shown below, the natural frequencies at port 2 are given by $s+2=0$ and $s+5=0$ without knowing which refers to open-circuit and which to short-circuit. Then the impedances Z_{11} and Z_{22} are given respectively by



- (a) $K_1 \frac{s+5}{s+2}, K_2 \frac{s+2}{s+5}$ (b) $K_1 \frac{s+2}{s+5}, K_2 \frac{s+5}{s+2}$
 (c) $K_1 \frac{s}{s+5}, K_2 \frac{s+2}{s+5}$ (d) $K_1 \frac{s+2}{s+5}, K_2 \frac{s+2}{s+5}$

12. If reflection coefficient for voltage be 0.6, the voltage standing wave ratio (VSWR) is

- (a) 0.66 (b) 4
 (c) 1.5 (d) 2

13. Consider the following statements:

Piezoelectric materials serve as

1. A source of ultrasonic waves.
2. When electric field is applied, the mechanical dimension of the substances are not at all altered.
3. Converts electrical energy to mechanical and vice versa.
4. Converts thermal energy to electrical energy.

Which of the above statements is/are correct?

- (a) 1 only (b) 2 and 3 only
 (c) 1 and 3 only (d) 1, 2, 3 and 4

14. A two-part network is defined by the relation:

$$I_1 = 5V_1 + 3V_2$$

$$I_2 = 2V_1 - 7V_2$$

The value of Z_{12} is

- (a) 3 (b) -3
 (c) $\frac{3}{41}$ (d) $\frac{2}{31}$

15. Consider the following statements:

1. The main shortcomings of diaphragms are that they are prone to shock vibrations.
2. Diaphragms have the advantages of high accuracy and good dynamic response.
3. Selection of material for diaphragm mainly depends upon temperature range and chemical nature of fluid coming in contact with diaphragm during pressure measurement.

Which of the above statements is/are correct?

- (a) 1, 2 and 3 (b) 2 and 3 only
 (c) 1 only (d) 1 and 2 only

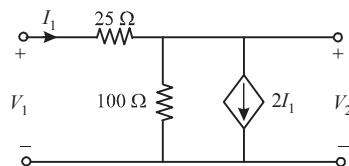
16. The Z-transform of $x(k)$ is given by

$$x(Z) = \frac{(1 - e^{-T})Z^{-1}}{(1 - z^{-1})(1 - e^{-T}Z^{-1})}$$

The initial value $x(0)$ is

- (a) zero (b) 1
 (c) 2 (d) 3

17. The Y-parameters of the network shown below are



- (a) $\begin{matrix} \rightarrow 0.04 & 0.04 \rightarrow \\ \equiv 0.04 & 0.03 \downarrow \end{matrix}$ (b) $\begin{matrix} \rightarrow -0.04 & -0.04 \rightarrow \\ \equiv 0.04 & -0.03 \downarrow \end{matrix}$
 (c) $\begin{matrix} \rightarrow -0.04 & -0.03 \rightarrow \\ \equiv 0.04 & 0.03 \downarrow \end{matrix}$ (d) $\begin{matrix} \rightarrow 0.04 & 0.03 \rightarrow \\ \equiv 0.04 & 0.03 \downarrow \end{matrix}$

18. Consider the following statements:

Piezoelectric materials

1. Crystal can be shown as electrical equivalent circuit similar to an inductor and a capacitor (Tank Circuit).
2. Quartz, Rochelle salt, tourmaline.
3. Used in voltage stabilizers.
4. This exhibits the reverse effect of electrostriction.

Which of the above statements are correct?

- (a) 1, 2 and 4 only (b) 1 and 2 only
 (c) 2 and 4 only (d) 1, 2, 3 and 4 only

19. A balanced RYB-sequence, Y-connected (Star connected) source with $V_{RN} = 100$ V is connected to a Δ -connected (Delta connected) balanced load of $(8 - j6)$ ohms per phase. Then the phase current and line current values respectively, are

- (a) 10 A; 30 A (b) $10\sqrt{3}$ A; 30 A
 (c) 10 A; 10 A (d) $10\sqrt{3}$ A; $10\sqrt{3}$ A

20. A resistance strain gage with factor (S_f) of 2 is bonded to a steel member, which is subjected to a strain of 1×10^{-6} . The original resistance value of this strain gage is 120 Ω . The change in resistance due to the applied strain is

- (a) 60 Ω (b) $240 \times 10^{-6} \Omega$
 (c) 240 Ω (d) $60 \times 10^{-6} \Omega$

21. A two-port network is described by the following equations:

$$V_1 = 50I_1 + 20I_2$$

$$V_2 = 30I_1 + 10I_2$$

Then, which one of the following is not correct?

- (a) $Z_{12} = 20$ (b) $Y_{12} = 0.2$
 (c) $h_{12} = 2.0$ (d) $A = 25$

22. Match list I with list II and select the correct answer using the code given below the lists:

List I

1. Hall effect
2. Light energy
3. Electric field
4. Applied voltage

List II

1. Varistor
2. Photodiodes
3. Measuring low magnetic field
4. Liquid crystal display

Codes:

	A	B	C	D
(a)	1	2	4	3
(b)	3	2	4	1
(c)	1	4	2	3
(d)	3	4	2	1

23. The system matrix of a continuous times system is given by

$$A = \begin{bmatrix} -0 & 1 \\ 3 & -5 \end{bmatrix} \text{ Then the characteristic equation is}$$

- (a) $s^2 + 5s + 3 = 0$ (b) $s^2 - 3s - 5 = 0$
 (c) $s^2 + 3s + 5 = 0$ (d) $s^2 + s + 2 = 0$

24. Consider the following statements:

The transfer impedances of a 2-port network remain constant when the position of excitation and response are interchanged of the network.

1. is linear
2. contains bilateral elements.
3. has high impedance.
4. is resonant

Which of the above statements is/are correct?

- (a) 1 and 2 only (b) 1, 3 and 4 only
 (c) 2 only (d) 1, 2, 3 and 4

25. When a ferromagnetic substance is magnetized, there are small changes in dimensions. The phenomenon is called

- (a) Hysteresis (b) Magnetostriction
 (c) Diamagnetism (d) Dipolar relaxation

26. For a parallel RLC circuit, if $R = 40 \Omega$, $L = 2H$ and $C = 0.5 F$, the bandwidth and quality factor are respectively

- (a) 20 rad/s, 0.05 (b) 10 rad/s, 20
 (c) 20 rad/s, 10 (d) 0.05 rad/s, 20

27. Consider the following statements:

1. Electromagnetic flowmeter is independent of liquid density.
2. Electromagnetic flowmeter cannot be employed for measuring flow of non-conducting fluids.

Which of the above statements is/are correct?

- (a) 1 only (b) Both 1 and 2
 (c) 2 only (d) Neither 1 nor 2

28. If a series RLC circuit resonates at 1.5 kHz and consumes 100 watts from a 100 volts a.c. source operating at resonant frequency with a bandwidth of 0.75 kHz; the values of R, L, and Q-factor of the circuit are respectively

- (a) 100Ω ; $\frac{0.2}{3\pi} H$; 2 (b) 50Ω ; $\frac{0.1}{2\pi} H$; 4
 (c) 100Ω ; $\frac{2}{3\pi} H$; 1 (d) 50Ω ; $\frac{0.3}{2\pi} H$; 3

29. Consider the following statements:

1. The main drawback of digital system is that the real world is mainly analog.
2. The major advantage of digital instruments over analog instruments is higher accuracy and better resolution.

3. Digital instruments are ordinarily used for the measurement of both analog and digital quantities.

Which of the above statements is/are correct?

- (a) 1, 2, 3 and 4 (b) 1 and 3 only
 (c) 2 only (d) 1 and 2 only

30. For a parallel resonant circuit. If the damped frequency is $\sqrt{8}$ rad/s and the bandwidth is 2 rad/s, the resonant frequency of the circuit is

- (a) 10 rad/s (b) 7 rad/s
 (c) 3 rad/s (d) 2 rad/s

31. The resonant frequency of an RLC series circuit is 1.5 MHz with the resonating capacitor of 150 pF. The bandwidth is 10 kHz. The effective value of the resistor is

- (a) 16.3 Ω (b) 9.5 Ω
 (c) 7.4 Ω (d) 4. Ω

32. A 4-digit DVM (digital voltmeter) with a 100-mV lowest full-scale range would have a sensitivity of how much value while resolution of this DVM is 0.0001?

- (a) 0.1 mV (b) 0.01 mV
 (c) 1.0 mV (d) 10 mV

33. For the network function,

$$T(s) = \frac{s}{s^2 + 2s + 100}, \text{ the resonant frequency and bandwidth are respectively}$$

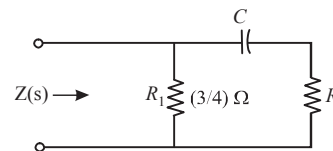
- (a) 10, 1 (b) 10, 2
 (c) 100, 1 (d) 100, 2

34. The state variable description of a linear autonomous system is $\dot{X} = AX$ where X is two-dimensional vector and A is a

matrix given by $A = \begin{bmatrix} -0 & -2 \\ 2 & 0 \end{bmatrix}$. The poles of the system are located at

- (a) -2 and $+2$ (b) $-j^2$ and $+j^2$
 (c) -2 and $+2$ (d) $+2$ and $+2$

35. For the circuit shown below, the two natural frequencies of the driving-point impedance $Z(s)$ are given by $s + 1 = 0$ and $s + 4 = 0$. It is not known, which is for open-circuit and which is for short-circuit. Then $Z(s)$ is given by which is for short-circuit. Then $Z(s)$ is given by



- (a) $\frac{3(s+4)}{16(s+1)}$ (b) $\frac{3(s+4)}{4(s+1)}$
 (c) $3 \frac{(s+1)}{(s+4)}$ (d) $\frac{1(s+4)}{3(s+1)}$

36. Match list I with list II and select the correct answer using the code given below the list:

List I

- A. Reed frequency meter
B. Weston Frequency materials
C. Weston Synchroscope
D. Ohm meter

Codes:

A	B	C	D
(a) 2	1	4	3
(b) 3	1	4	2
(c) 2	3	4	1
(d) 3	4	1	2

37. A transfer function has a zero at $a = -1$ and poles at $s = -1 \pm j1$. The multiplier being unity, if the input is unit step function, the steady state response is given by
(a) $0.5\angle 0^\circ$ (b) $1.0\angle 0^\circ$
(c) $2.0\angle 0^\circ$ (d) $2.0\angle 90^\circ$

38. Match list I with list II and select the correct answer using the code given below the lists:

List I

- A. Ferro-electric materials
B. Anti-Ferroelectric materials
C. Ferrites
D. Ferro-magnetic materials

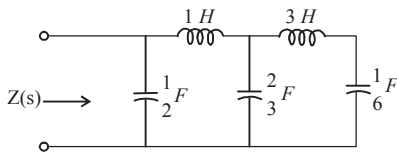
List II

1. Neel temperature
2. Magnetostrictive transducers
3. Magnetocaloric effect
4. Cannot be shaped by ordinary machining process

Codes:

A	B	C	D
(a) 2	1	4	3
(b) 3	1	4	2
(c) 2	3	4	1
(d) 3	4	1	2

39. For the circuit shown, the values of $Z(s)$ as $s \rightarrow 0$ and $s \rightarrow \infty$ are respectively given by



- (a) $\frac{2}{s}, s$ (b) $\frac{6}{8s}, \frac{2}{s}$
(c) $\frac{8s}{6}, \frac{s}{2}$ (d) $4s + \frac{6}{s}, \frac{2}{s}$

40. The precision of a ramp type digital voltmeter depends on
(a) frequency of the generator and slope of the ramp.
(b) frequency of the generator.
(c) slope of the ramp.
(d) switching time of the gate.
41. The transfer function of a phase-lead compensator is given by $G(s) = \frac{1 + 3Ts}{1 + Ts}$, $T > 0$. The maximum phase shift provided by such a compensator is

List II

1. moving iron
2. Vibrating
3. Moving coil
4. Electrodynamic

- (a) 90° (b) 60°
(c) 45° (d) 30°

42. Match list I with list II and select the correct answer using the code given below the lists:

List I

- A. Iron loss of a choke carrying A.C. current at 50 Hz along with D.C.
B. Calibration of a dynamometer
C. Dielectric loss of a capacitor at 20 Hz
D. Power loss of an insulator test at high voltage

List II

1. Electrostatic wattmeter
2. Oscilloscope
3. D.C. Potentiometer
4. A.C. Potentiometer

Codes:

A	B	C	D
(a) 3	1	4	2
(b) 2	1	4	3
(c) 3	4	1	2
(d) 2	4	1	3

43. If the initial voltage across the capacitor of 2 Farad is $V(0) = 1$, the voltage and charge on the capacitor at $t = 3$ sec after connecting a current source $I_s = 2A$ at $t = 0$ are respectively
(a) 2 V, 4 coulomb (b) -2 V, 4 coulomb
(c) 4 V, 8 coulomb (d) 8 V, 4 coulomb

44. Consider the following statements:

The coercive force can be increased by

1. Adding Cobalt because it is a ferromagnetic material.
2. Adding Gold because it is a diamagnetic material.
3. Adding super alloy
4. Space charge polarizing.

Which of the above statements is/are correct?

- (a) 1, 2, 3 and 4 (b) 1 only
(c) 2 only (d) 1 and 3 only

45. If load impedance is 100 ohm and input impedance is 25 ohm, then the characteristic impedance of the transmission line is

- (a) 70 ohm (b) 60 ohm
(c) 50 ohm (d) 40 ohm

46. Temperature below which certain materials are anti-ferromagnetic is called

- (a) Curie temperature (b) Neel temperature
(c) Wein temperature (d) Debye temperature

47. Consider the following statements:

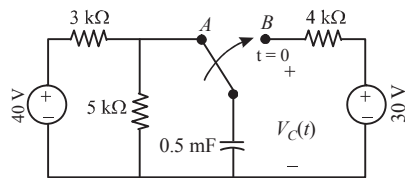
A step voltage is applied to an under-damped series RLC circuit in which R is variable. If R is

1. increased, the steady-state voltage across C will be reduced.
2. increased, the frequency of transient oscillations across C will be reduced.
3. reduced, the transient oscillations will die down at a fast rate.

Which of the above statements is/are correct?

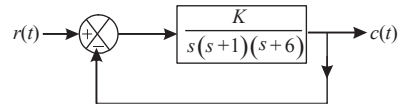
- (a) 2 only (b) 4 only
(c) 2 and 4 only (d) 1, 2, 3 and 4

48. A moving coil ammeter having a resistance of 1 ohm gives full scale deflection when a current of 10 mA is passed through it. The instrument can be used for the measurement of voltage up to 10 V by
- (a) connecting a resistance of 999 ohm in series with the instrument
(b) connecting a resistance of 999 ohm parallel to the ammeter
(c) connecting resistance of 999 ohm parallel to the load
(d) connecting a resistance of 1000 ohm in series with the load
49. For the circuit shown below, the switch has been in position A for a long time. At $t = 0$, the switch is moved to B. Then, the capacitor voltage $V_c(t)$ for $t > 0$ is

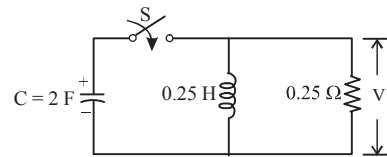


- (a) $V_c(t) = (24 - 6e^{-2t})V$ (b) $V_c(t) = (230 - 15e^{-0.5t})V$
(c) $V_c(t) = (6 - 6e^{-2t})V$ (d) $V_c(t) = (30 - 5e^{-0.5t})V$

50. Consider the following statements:
Electrets are the materials which are
1. having permanent electric moments.
 2. electromagnets.
 3. very similar to permanent magnet materials.
 4. similar to anti-ferroelectric materials
- Which of the above statements is/are correct?
- (a) 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2, 3 and 4
51. Consider the following statements:
Magnetic susceptibility
1. depends on the nature of the magnetic material.
 2. is not dependent on the relative permeability of the medium.
 3. cannot be determined by measuring the force exerted on a magnetic material when placed in a magnetic field
 4. can be determined from $M-H$ curve.
- Which of the above statements is/are correct?
- (a) 1, 2, 3 and 4 (b) 1 only
(c) 1 and 4 only (d) 2 only
52. For a series RLC circuit energized with a sinusoidal voltage source of frequency 4 rad/s, the applied voltage lags the current by an angle of $\tan^{-1} 2$ degrees. Then the value of R for $L = 1H$ and $C = 0.05 F$ is
- (a) 4.0 ohm (b) 2.0 ohm
(c) 1.0 ohm (d) 0.5 ohm
53. The feedback system shown below is stable for all value of K given by



- (a) $K > 0$ (b) $K < 0$
(c) $0 < K < 42$ (d) $0 < K < 60$
54. The value of the multiplier resistance for a dc voltmeter, having 50V range with $5 k\Omega/V$ sensitivity, employing a 200 μA meter movement and having internal resistance of 100 Ω is given by
- (a) 249.9 $k\Omega$ (b) 200 Ω
(c) 200 $k\Omega$ (d) 2.5 $k\Omega$
55. For the given circuit, the initial inductor current and the voltage across the capacitor are zero and 2, respectively. When the switch S is closed at $t = 0$, the values of v and $\frac{dv}{dt}$ are, respectively



- (a) 2, -4 (b) 0, 0.25
(c) 0, -0.5 (d) 2, 0
56. Match list I with list II and select the correct answer using the code given below the lists:
- | List I | | List II | |
|----------------------|-----------------|---------|--|
| A. Enamel Converting | 1. Laminations | | |
| B. Insulation | 2. Wires | | |
| C. Fibrous materials | 3. Machines | | |
| D. Empire cloth | 4. Transformers | | |
- Codes:**
- | | A | B | C | D |
|-----|---|---|---|---|
| (a) | 2 | 4 | 1 | 3 |
| (b) | 3 | 4 | 1 | 2 |
| (c) | 2 | 1 | 4 | 3 |
| (d) | 3 | 1 | 4 | 2 |
57. For an A.C. circuit, if $v(t) = 160 \sin(\omega t + 10^\circ)$ and $i(t) = 5 \sin(\omega t - 20^\circ)$, the reactive power absorbed by the circuit is
- (a) 100 VARs (b) 200 VARs
(c) 300 VARs (d) 400 VARs
58. A signal of 10 V is applied to a 50 ohm coaxial transmission line, terminated in a 100 ohm load. The voltage reflection coefficient is
- (a) $\frac{1}{4}$ (b) $\frac{1}{3}$
(c) $\frac{1}{2}$ (d) 1
59. Consider the following statements:
Factors affecting the dielectric loss are
1. directly proportional to the frequency of supply voltage
 2. inversely proportional to the supply frequency.

3. inversely proportional to the square of the supply voltage
4. directly proportional to the square of the square of the supply voltage.

Which of the above statements are correct?

- (a) 1 and 3 only
- (b) 2 and 3 only
- (c) 2 and 4 only
- (d) 1 and 4 only

60. A conductor 2 metre long lies along the Z-axis with a current of 10 A in a_z direction. If the magnetic field is $\vec{B} = 0.05 a_x T$, the force on the conductor is

- (a) $4.0 a_y N$,
- (b) $1.0 a_z N$,
- (c) $1.0 a_y N$,
- (d) $3.0 a_z N$,

61. Using Routh's criterion, the number of roots in the right half S-plane for the characteristic equation:

$$S^4 + 2s^3 + 2s^2 + 3s + 6 = 0 \text{ is}$$

- (a) one
- (b) two
- (c) three
- (d) four

62. Match list I with list II and select the correct answer using the code given below the lists:

List I

- A Electrostatic
- B Induction
- C Dynamometer
- D Thermal

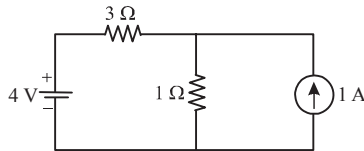
List II

1. Power at 50 Hz only
2. Power at frequencies ranging from dc to RF
3. Power at unity power factor and at high value
4. Power at frequencies ranging from dc to 150 Hz

Codes:

A	B	C	D
(a) 3	1	4	2
(b) 2	1	4	3
(c) 3	4	1	2
(d) 2	4	1	3

63. For the circuit shown, the voltage across the 1 ohm resistor is given by



- (a) $\frac{7}{4} V$
- (b) $\frac{5}{4} V$
- (c) $\frac{7}{3} V$
- (d) $\frac{2}{3} V$

64. Consider the following statements:

Characteristics of a good insulating material are

1. Should give uniform electric and thermal properties.
2. High permittivity.
3. Low dissipation factor.
4. Low insulating resistance.

Which of the above statements are correct?

- (a) 1 and 4 only
- (b) 2 and 4 only
- (c) 1 and 3 only
- (d) 1, 2, 3 and 4

65. At a measuring frequency of 10^{12} Hz, the dielectric constant of a material will be due to

- (a) Electronic polarization
- (b) Ionic polarization
- (c) Electronic and Ionic polarization
- (d) Electronic, Ionic and Orientational

66. A load is connected to an active network. At the terminals to which the load is connected. $R_{th} = 10 \Omega$ and $V_{th} = 60 V$. Then the maximum power supplied to the load is

- (a) 360 W
- (b) 90 W
- (c) 60 W
- (d) 10 W

67. A basic D' Arsonval movement with a full scale deflection of $50 \mu A$ and internal resistance of $500 k\Omega$ is used as voltmeter. The value of the multiplier resistance needed to employ this meter to measure a voltage range of $(-10) V$ is given by

- (a) $100 k\Omega$
- (b) $500 k\Omega$
- (c) $199.5 k\Omega$
- (d) $2 \times 10^5 k\Omega$

68. The feedback control system represented by the open loop

$$\text{transfer function } G(s)H(s) = \frac{10(s+2)}{[(s+1)(s+3)(s-5)]} \text{ is}$$

- (a) unstable
- (b) stable
- (c) marginally stable
- (d) insufficient data

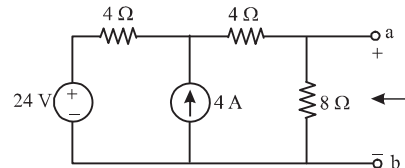
69. Consider the following statements regarding measurement of 3-phase power by two-wattmeter method; one of the wattmeter reads negative implying:

1. Power factor is less than 0.5.
2. Power flow is in the reverse direction.
3. Load power factor angle is greater than 60°
4. Load is unbalanced.

Which of the above statements are correct?

- (a) 1 and 2 only
- (b) 2 and 3 only
- (c) 1 and 3 only
- (d) 1, 2, 3 and 4 only

70. Applying Norton's Theorem, the Norton's equivalent circuit to the left of the terminals a and b in the below circuit is having equivalent current source (I_N) and equivalent resistance (R_N) as



- (a) $I_N = 5 A$; $R_N = 4 \Omega$
- (b) $I_N = 4 A$; $R_N = 6 \Omega$
- (c) $I_N = 9 A$; $R_N = 1.6 \Omega$
- (d) $I_N = 4 A$; $R_N = 3 \Omega$

71. The property characteristic of ferroelectric materials is

- (a) Dielectric relaxation
- (b) Dielectric breakdown
- (c) Spontaneous polarization
- (d) Spontaneous magnetization

72. A uniform plane wave is propagating in a material for which $\epsilon = 4\epsilon_0$, $\mu = 7\mu_0$ and $\sigma = 0$. The skin depth of the material is
 (a) zero (b) infinity
 (c) 28 m (d) 14 m

73. Consider the following statements about superconductors:

1. The temperature at which the conductor become a superconductors is called transition temperature.
2. Superconductors repel magnetic flux lines.
3. All superconductors are paramagnetic materials.
4. Superconductors become normal when placed in a magnetic field of certain critical value.

Which of the above statements are correct?

- (a) 1 and 2 only (b) 2 and 4 only
 (c) 1, 2 and 4 only (d) 1, 2, 3 and 4

74. Consider the following statements in connecting with the closed-loop poles of feedback control system:

1. Poles on $j\omega$ -axis will make the output amplitude neither decaying nor growing in time.
2. Dominant closed-loop poles occur in the form of a complex conjugate pair.
3. The gain of a higher order system is adjusted so that there will exist a pair of complex conjugate closed-loop poles on $j\omega$ -axis.
4. The presence of complex conjugate closed-loop poles reduces the effects of such non-linearities as dead zones, backlash and coulomb friction.

Which of the above statements is/are correct?

- (a) 2 only (b) 2, 3 and 4 only
 (c) 1, 2 and 4 only (d) 1, 2, 3 and 4

75. The sensitivity of 200 μA meter movement when it is used as a dc voltmeter is given by

- (a) 500 $\Omega/\text{m V}$ (b) 5 Ω/V
 (c) 0.5 $\Omega/\text{m V}$ (d) 5 $\Omega/\text{m V}$

76. Consider a unity feedback control system with open-loop transfer function $G(s) = \frac{K(s+1)}{S(s+2)(s+3)}$. The steady-state

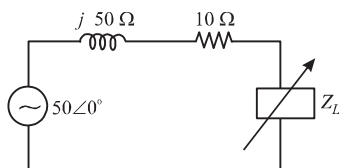
error of the system due to a unit step input is

- (a) zero (b) $K/6$
 (c) $6/K$ (d) infinite

77. A 1 mA meter movement with an internal resistance of 100 Ω is to be converted into (0-100) mA. To achieve this, value of shunt resistance R_{sh} is given by.

- (a) 1 $k\Omega$ (b) 200 $k\Omega$
 (c) 1.01 $k\Omega$ (d) 1.01 $k\Omega$

78. The maximum power that can be transferred in the load Z_L in the below circuit is



- (a) 12.25 W (b) 62.5 W
 (c) 24.5 W (d) 500 W

79. Match list I with list II and select the correct answer using the code given below the list:

List I

- A. Precision Work
 B. Rheostat
 C. Heating devices
 D. Brushes

List II

1. Graphite
 2. Nichrome
 3. Constantan
 4. Magnesium

Codes:

A	B	C	D
(a) 4	3	2	1
(b) 1	3	2	4
(c) 4	2	3	1
(d) 1	2	3	4

80. Consider the following statements:

1. In conducting medium, the field attenuates exponentially with increasing depth.
2. Conduction medium behaves like an open circuit to the electromagnetic field.
3. In lossless dielectric, relaxation time is infinite.
4. In charge-free region, the Poisson's equation becomes Laplace's equation.

Which of the above statements are correct?

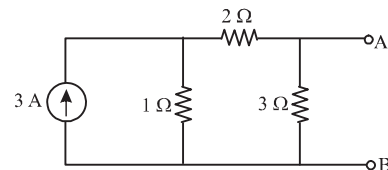
- (a) 1, 2, and 3 only (b) 1, 3 and 4 only
 (c) 2, 3 and 4 only (d) 1, 2, 3 and 4

81. In a Hexagonal Close Packed (HCP) crystal structure. If 'c' represent, respectively the short and long unit cell dimensions

the $\frac{c}{a}$ ratio should be

- (a) 12.00 (b) 0.74
 (c) 1.6333 (d) 16.33

82. The Thevenin's equivalent of the circuit shown below is



- (a) 0.75 V, 1.5 Ω (b) 15 V, 1.5 Ω
 (c) 15 V, 0.75 Ω (d) 5.0 V, 1.5 Ω

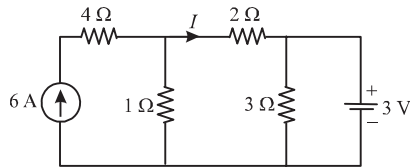
83. Consider the following statements about hot-wire instruments:

1. They read equally well on dc and/or ac circuits.
2. They are simple and rudest in construction and power consumption is low.
3. They are quite suitable for measurement of currents at very high frequencies.

Which of the above statements are correct?

- (a) 1 and 2 only (b) 2 and 3 only
 (c) 1 and 3 only (d) 1, 2, 3 and 4

84. For the circuit shown below,
- I
- is



- (a) 0 A (b) 1 A
(c) 2 A (d) 3 A

85. A semiconductor has a band gap of 2 eV. The wavelength of radiation emitted from the semiconductor when electrons and holes recombine is

- (a) 625 nm (b) 625 μm
(c) 625 mm (d) 625 cm

86. In free space
- $E(Z, t) = 60\pi \cos(\omega t - \beta Z) \hat{a}_x$
- V/m. The average power crossing a circuit area of
- π
- square meters in the plane
- $Z = \text{constant}$
- is

- (a) 16π watts/ m^2 (b) 15π watts/ m^2
(c) 14π watts/ m^2 (d) 13π watts/ m^2

87. Match list I with list II and select the correct answer using the code given below the lists:

List I

- A Metals
B Semiconductors
C Insulators
D Ferroelectric crystals

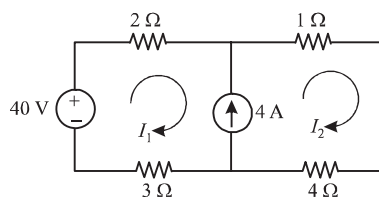
List II

1. Are in spontaneously polarized state
2. Finite forbidden gap
3. Smaller forbidden gap
4. Partially filled bands

Codes:

A	B	C	D
(a) 4	3	2	1
(b) 1	3	2	4
(c) 4	2	3	1
(d) 1	2	3	4

88. The currents
- I_1
- and
- I_2
- in the below circuit are respectively



- (a) 4 A; 4 A (b) 3 A; 5 A
(c) 2 A; 6 A (d) 6 A; 2 A

89. A (0 – 25) Amp ammeter has a guaranteed accuracy of 1 percent of full scale reading. The current measured by this ammeter is 10 Amp. The limiting error in percentage for this instrument is

- (a) 2.5 % (b) 0.5 %
(c) 0.25 % (d) 0.025 %

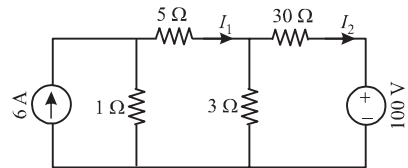
90. Given a unity feedback system with
- $G(s) = \frac{K}{s(s+4)}$
- , the value of K for damping ratio of 0.5 is

- (a) 1 (b) 16
(c) 4 (d) 2

91. The pressure in a tank varies from 20 psi to 100 psi. Further, pressure in the tank is desired to be kept at 50 psi. The full scale error, when pressure inside the tank is 30 psi, is given by

- (a) –62.5% (b) 25%
(c) 80% (d) –2.5%

92. The current
- I_1
- and
- I_2
- in the below circuit are respectively



- (a) 1.818 A; –0.4545 A (b) 2.451 A; –1.568 A
(c) 0.4545 A; –1.818 A (d) 1.56 A; –2.45 A

93. The following data are obtained by measurement on gold:

Density = 19.32 gm/cc

Resistivity = $2.42 \mu\Omega/\text{cm}$

Atomic weight = 197.2

The mobility of electrons in gold is

- (a) $4.39 \times 10^{-3} \text{ m}^2/\text{V} \cdot \text{sec}$ (b) $4.39 \times 10^{-2} \text{ m}^2/\text{V} \cdot \text{sec}$
(c) $4.39 \text{ m}^2/\text{V} \cdot \text{sec}$ (d) $4.39 \times 10^3 \text{ m}^2/\text{V} \cdot \text{sec}$

94. A magnetic field
- $\vec{B}$
- of 2 T is normal to a copper strip 0.5 mm thick carrying an electron current of 40 A. If the electron density is
- 10.0×10^{28}
- per cubic metre, the voltage across the strip in micro volt is

- (a) 40 (b) 30
(c) 20 (d) 10

95. Match list I with list II and select the a correct answer using the code given below the lists:

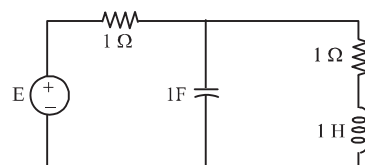
List I

- A High conductivity materials
B High resistivity materials
C Metals for lightly loaded contacts
D Materials for bimetallic strip

List II

1. Tungsten, Carbon
2. Platinum
3. Aluminium, Copper
4. Iron, Nickel, Constantan

96. If the power dissipated in the circuit shown below is 8 W, then the value of E will be

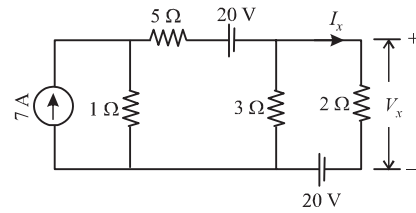


- (a) 2 V (b) 4 V
(c) 8 V (d) 16 V

97. A resistance of 105 ohms is specified using significant figure as indicated below:
- 105 ohms
 - 105.0 ohms
 - 0.000105 $\mu\Omega$
98. Consider the following statements in connection with pole location:
- A distinct pole always lies on the real axis.
 - A dominant pole has a large time constant.
- Which of the above statements is/are correct?
- (a) Both 1 and 2 (b) Neither 1 nor 2
(c) 1 only (d) 2 only
99. A (0 – 250) V voltmeter has a guaranteed accuracy of 2 per cent of full scale reading. The voltage measured by this voltmeter is 150 volts. The limiting error in percentage is

- (a) 2.5 % (b) 0.05 %
(c) 3.33 % (d) 5.0 %

100. The current I_x and voltage V_x in the below circuit are respectively



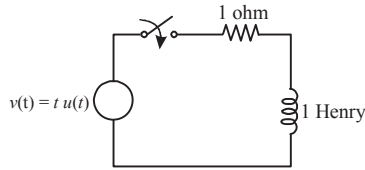
- (a) 5 A; 10 V
(b) 10 A; 20 V
(c) 6 A; 12 V
(d) 4 A; 8V

ANSWER KEYS

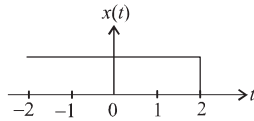
1. (c)	2. (b)	3. (c)	4. (b)	5. (d)	6. (a)	7. (d)	8. (c)	9. (b)	10. (c)
11. (c)	12. (b)	13. (c)	14. (c)	15. (a)	16. (a)	17. (b)	18. (d)	19. (b)	20. (b)
21. (d)	22. (b)	23. (a)	24. (a)	25. (b)	26. (d)	27. (c)	28. (a)	29. (a)	30. (c)
31. (d)	32. (b)	33. (b)	34. (b)	35. (a)	36. (a)	37. (a)	38. (d)	39. (a)	40. (a)
41. (d)	42. (b)	43. (c)	44. (b)	45. (c)	46. (b)	47. (c)	48. (a)	49. (d)	50. (c)
51. (c)	52. (d)	53. (c)	54. (a)	55. (a)	56. (b)	57. (b)	58. (b)	59. (d)	60. (c)
61. (b)	62. (a)	63. (a)	64. (c)	65. (a)	66. (b)	67. (c)	68. (a)	69. (c)	70. (a)
71. (c)	72. (b)	73. (c)	74. (c)	75. (d)	76. (a)	77. (c)	78. (b)	79. (b)	80. (d)
81. (c)	82. (b)	83. (c)	84. (b)	85. (a)	86. (b)	87. (a)	88. (c)	89. (a)	90. (b)
91. (a)	92. (c)	93. (a)	94. (d)	95. (a)	96. (b)	97. (d)	98. (a)	99. (c)	100. (a)

TEST PAPER 7

1. The current in the below network is



- (a) $|t - 1 + e^{-t}|u(t)$ (b) $|t^2 - t + e^{-t}|u(t)$
 (c) $|t + 1 + e^{-t}|u(t)$ (d) $|t - 1 - e^{-t}|u(t)$
2. When waves travel along a transmission line from a generator to a load, through which region is power transmission taking place?
- (a) Only through the conducting region
 (b) Only through the non-conducting regions.
 (c) Both through conducting and non-conducting regions.
 (d) Through the conducting regions for half a cycle and through the non-conducting regions for the next half cycle.
- 3.



The mathematical model of the above shown signal is

- (a) $x(t) = u(2 + t)$ (b) $x(t) = u(t - 2)$
 (c) $x(t) = u(2 - t)$ (d) $x(t) = u(t - 1)$
4. Consider the following statements:
- Power factor will be unity.
 - Current in circuit will be maximum.
 - Current in circuit will be minimum.
- Which of these statements are correct with respect to resonance in R-L-C parallel circuit?
- (a) 1, 2 and 3 (b) 1 and 2 only
 (c) 2 and 3 only (d) 1 and 3 only
5. Number of state variables of discrete time system, describe by $y[n] - \frac{3}{4}y[n-1] + \frac{1}{8}y[n-2] = x[n]$ is
- (a) 2 (b) 3
 (c) 4 (d) 1
6. Which of the following pair of values of L and C should be used in a tank circuit to obtain a resonant frequency of 8 kHz? The bandwidth is 800 Hz and winding resistance of the coil is 10 ohms.
- (a) 12 mH and 1 μ F (b) 10 H and 0.2 μ F
 (c) 1.99 mH and 0.2 μ F (d) 1.99 mH and 10 μ F
7. An elliptically polarized wave travelling in the positive Z-direction in air has x and y components.

$$E_x = 3 \sin(\omega t - \beta z) V/m$$

$$E_y = 6 \sin(\omega t - \beta z + 75^\circ) V/m$$

If the characteristic impedance of air is 360Ω , the average power per unit area conveyed by the wave is

- (a) $8 W/m^2$ (b) $4 W/m^2$
 (c) $62.5 mW/m^2$ (d) $125 mW/m^2$
8. The value of a resistance as measured by a Wheatstone bridge is 10.0 K using a voltage source of 10.0 V. The same resistance is measured by the same bridge using 15.0 V. The value of resistance is
- (a) 15.0 K (b) 15.5 K
 (c) 16.6 K (d) 10.0 K
9. In the case of ABCD parameters, if all the impedances in the network are doubled, then
- (a) A and D remain unchanged, C is halved and B is doubled.
 (b) A, B, C and D are doubled.
 (c) A and B are doubled, C and D are unchanged
 (d) A and D are unchanged, C is doubled and B is halved.

10. Unit step response of the system described by the equation $y(n) + y(n-1) = x(n)$ is

(a) $\frac{Z^2}{(Z+1)(Z-1)}$ (b) $\frac{Z}{(Z+1)(Z-1)}$
 (c) $\frac{Z+1}{Z-1}$ (d) $\frac{Z(Z-1)}{(Z+1)}$

11. The transfer functions for the state representation of continuous time LTI system:

$$q(t) = Aq(t) + bx(t)$$

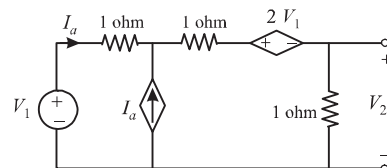
$$y(t) = cq(t) + dx(t)$$

is given by

(a) $c(sI - A)^{-1}b + d$ (b) $b(sI - A)^{-1}b + d$
 (c) $c(sI - A)^{-1}b + d$ (d) $d(sI - A)^{-1}b + c$

12. The diffusion length for holes L_p is the
- (a) Average distance which an injected hole travels before recombining with an electron.
 (b) Maximum distance travelled by a hole before recombining with an electron.
 (c) Length of the region in which diffusion takes place.
 (d) Minimum distance travelled by a hole before it recombines with an electron.

- 13.



The above network contains resistors and controlled sources.

$$G_{12} = \frac{V_2}{V_1} \text{ is}$$

- (a) $-\frac{4}{5}$ (b) $-\frac{3}{5}$
(c) $-\frac{2}{5}$ (d) $-\frac{1}{5}$

14. The frequency response $H(\Omega)$ of a system for impulse sequence response $h[n] = \delta[n] + \delta[n-1]$ is

- (a) $H(\Omega) = \cos \frac{\Omega}{2} - \frac{\Omega}{2}$
(b) $H(\Omega) = 2 \cos \Omega - \frac{\Omega}{2}$
(c) $H(\Omega) = 2 \cos \Omega - \frac{\Omega}{2}$
(d) $H(\Omega) = 2 - \frac{\Omega}{2}$

15. Consider the following statements:

The inter element spacing of

- More than λ in array antenna will produce grating lobes in unscanned condition.
- More than $\lambda/2$ but less than λ in array antenna will produce grating lobe under scanned condition.
- Less than $\lambda/2$ in array antenna will not produce any grating lobe.
- More than 1.5λ in array antenna will not produce any grating lobe.

Which of the above statements are correct?

- (a) 1 and 2 only (b) 2 and 3 only
(c) 3 and 4 only (d) 1, 2, 3 and 4

18. The magnetic flux density B and the vector magnetic potential A are related as

- (a) $B = \nabla \cdot A$ (b) $A = \nabla \cdot B$
(c) $B = \nabla \times A$ (d) $A = \nabla \times B$

19. Two milli ammeters with full scale currents of 1mA and 10 mA are connected in parallel and they read 0.5 mA and 2.5 mA respectively. Their internal resistance are in the ratio of

- (a) 1: 10 (b) 1: 1
(c) 1: 5 (d) 5: 1

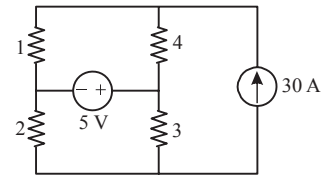
20. The Fourier transform of unit step sequence is

- (a) $\pi \delta(\Omega)$ (b) $\frac{1}{1 - e^{-j\Omega}}$
(c) $\pi \delta(\Omega) + \frac{1}{1 - e^{-j\Omega}}$ (d) $1 - e^{-j\Omega}$

21. A long 1 metre thick dielectric ($\epsilon = 3 \epsilon_0$) slab occupying the region $0 \leq x \leq 5$ is placed perpendicularly in a uniform electric field $\vec{E}_0 = 6\vec{a}_x$. The polarization $\vec{P}$ inside the dielectric is

- (a) $4 \epsilon_0 \vec{a}_x$ (b) $8 \epsilon_0 \vec{a}_x$
(c) $36 \epsilon_0 \vec{a}_x$ (d) Zero

22.



The power dissipated in the 1Ω resistor is 1W due to the 5 V voltage source alone and 576 W due to 30 A current source alone. The total power absorbed in the same resistor due to both the source is

- (a) 577 W (b) 575 W
(c) 625 W (d) 529 W

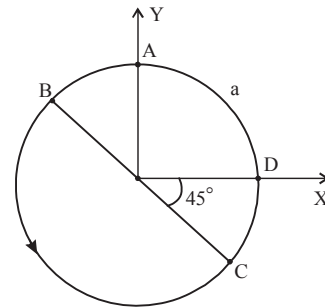
23. Consider the following statements regarding an FET:

- Its operation depends upon the flow of majority carriers only.
- It has a high input resistance.
- It is suitable for high frequency.
- Its operation depends upon the flow of both majority carriers.

Which of the above statements are correct?

- (a) 1, 2, 3 and 4 (b) 1 and 2 only
(c) 2 and 3 only (d) 3 and 4 only

24.



Consider points A, B, C and D on a circle of radius 2 units as in the above figure. The items in list II are the values of $\vec{a}_\phi$ at different points on the circle. Match list I with list II and select the correct answer using the code given below the lists:

List I

- A.
B.
C.
D.

List II

- $\vec{a}_x$
- $\vec{a}_y$
- $-\vec{a}_x$
- $-(\vec{a}_x + \vec{a}_y)/\sqrt{2}$
- $-(\vec{a}_x - \vec{a}_y)/\sqrt{2}$
- $(\vec{a}_x - \vec{a}_y)/\sqrt{2}$

Codes:

A	B	C	D
(a) 3	4	5	2
(b) 1	6	5	2
(c) 1	6	2	4
(d) 3	5	4	2

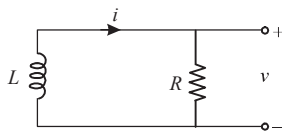
25. The *incorrect* statement is
 (a) Thermistor has a high sensitivity.
 (b) Thermocouple does not require an external electrical source for its operation.
 (c) Platinum has a linear R-T relationship.
 (d) Thermistor does not require an external electrical source for its operation.
26. In ionic crystals, electrical conductivity is
 (a) Very high
 (b) Depends on material
 (c) Depends on temperature
 (d) Practically zero
27. Consider the following statements:
 1. The Laplace transform of the unit impulse function is $s \times$ Laplace transform of the unit ramp function.
 2. The impulse function is a time derivative of the ramp function.
 3. The Laplace transform of the unit impulse function is $s \times$ Laplace transform of the unit step function.
 4. The impulse function is a time derivative of the unit step function.

Which of the above statements are correct?

- (a) 1 and 2 only (b) 3 and 4 only
 (c) 2 and 3 only (d) 1, 2, 3 and 4
28. The flux and potential functions due to a line charge and due to two concentric circular conductors are of the following form:
 (a) Concentric circular equipotential lines and straight radial flux lines.
 (b) Concentric circular flux lines and straight equipotential lines.
 (c) Equipotentials due to line charge are concentric cylinders and equipotentials due to two conductors are concentric cylinders

29. LED is a
 (a) p-n diode (b) Thermistor
 (c) Gate (d) Transistor

30.

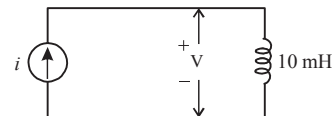


Voltage and current expressions for the above circuit are given at $t \geq 0$ as $v = 125e^{-50t}V$, $i = 5e^{-50t}A$. The value of L will be

- (a) 0.005 H (b) 0.05 H
 (c) 0.5 H (d) 5 H
31. Consider the following statements:
 Fourier series of any periodic function $X(t)$ can be obtained if
 (a) $\int_0^1 |x(t)| dt < \infty$
 (b) Finite number of discontinuities exist within finite time interval t.
 Which of the above statements is/are correct?
 (a) 1 only (b) 2 only
 (c) Both 1 and 2 (d) Neither 1 nor 2

32. In a variable type carbon resistor, the carbon track is formed of a mixture of carbon, resin and
 (a) Clay (b) Manganese
 (c) Nickel (d) Cadmium
33. A standard air filled waveguide WR-187 has inside wall dimensions of $a = 4.755$ cm and $b = 2.215$ cm. At 12 GHz, it will support
 (a) TE_{10} mode only.
 (b) TE_{10} and TE_{20} modes only.
 (c) TE_{10} , TE_{20} and TE_{01} modes only.
 (d) TE_{10} , TE_{20} , TE_{01} and TE_{11} modes
34. A single strain of resistance 120Ω is mounted along the axial direction of an axially loaded specimen of steel ($E = 200$ GPa). The percentage change in length of the rod due to loading is 3% and the corresponding change in resistivity of strain gauge material is 0.3%. For a Poisson's ratio of 0.3, the value of the gauge factor is
 (a) 1-3 (b) 1-5
 (c) 1-7 (d) 2-0

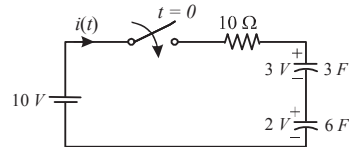
35.



In the above shown circuit, the independent current source generates zero current for $t > 0$. At what instant of time, will the current attain the maximum value in the circuit?

- (a) 0-25 sec (b) 0-5 sec
 (c) 1 sec (d) 2 sec
36. Frequency scaling (relationship between discrete time frequency (Ω) and continuous time frequency (ω)) is defined as
 (a) $\omega = 2\Omega$ (b) $\omega = 2T_s/T$
 (c) $\Omega = 2\omega/T_s$ (d) $\Omega = \omega T_s$
37. The intrinsic impedance of copper at 3 GHz with parameters: $\mu = 4\pi \times 10^{-7} H/m$; $\epsilon = 10^{-9}/36\pi$; and $\sigma = 5.8 \times 10^7 mho/m$ Will be
 (a) $0.02e^{j\pi/4} ohm$ (b) $0.02e^{j\pi/2} ohm$
 (c) $0.2e^{j\pi/2} ohm$ (d) $0.2e^{j\pi/4} ohm$

38.



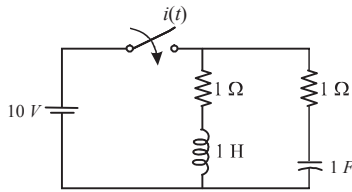
In the circuit shown above, switch S is closed at $t = 0$. The time constant of the circuit and initial value of current $i(t)$ are

- (a) 30 sec, 0.5 A (b) 60 sec, 1.0 A
 (c) 90 sec, 1.0 A (d) 20 sec, 0.5 A
39. A voltage source of 240 volts having an internal impedance of $(3 - j4)\Omega$ is supplying power to a complex load impedance Z_L . What will be the maximum power transferred to the load?
 (a) 2.4 kW (b) 3.6 kW
 (c) 4.8 kW (d) 6.0 kW

40. Atomic number of silicon is

- (a) 12 (b) 13
(c) 14 (d) 15

41.



The value of the current $i(t)$ in amperes in the above circuit is

- (a) 0 (b) 10
(c) $10e^{-t}$ (d) $0(1 - e^{-t})$

42. A short current element has length $= 0.03\lambda$, where λ is the wavelength. The radiation resistance of uniform current distribution is

- (a) $0.072\pi^2\Omega$ (b) $80\pi^2\Omega$
(c) 72Ω (d) 80Ω

43. If random process $X(t)$ and $Y(t)$ are orthogonal then

- (a) $S_{XY}(f) = 0$ (b) $S_{XY}(f) = S_X(f) = S_Y(f)$
(c) $R_{XY}(\tau) = h(\tau)$ (d) $H(f) = 0$

44. A first order circuit is excited with a dc source. The current $i(t)$ through any element of the circuit can be written as (i_f and i_i are the final and initial values, respectively, of the current)

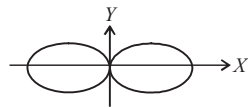
- (a) $i_i - (i_i - i_f)e^{-\frac{t}{T}}$ (b) $i_f - (i_f - i_i)e^{-\frac{t}{T}}$
(c) $i_i - (i_f - i_i)e^{-\frac{t}{T}}$ (d) $i_f - (i_i - i_f)e^{-\frac{t}{T}}$

45. Match list I with list II and select the correct answer using the code given below the list:

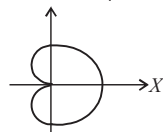
List I

List II

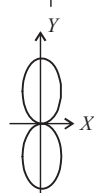
A. $\frac{d}{\lambda} = 0.25, a = 90^\circ$



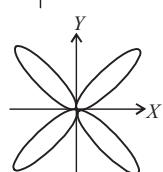
B. $\frac{d}{\lambda} = 0.5, a = 0^\circ$



C. $\frac{d}{\lambda} = 0.5, a = 180^\circ$



D. $\frac{d}{\lambda} = 1.0, a = 180^\circ$



Codes:

A	B	C	D
(a) 4	3	1	2
(b) 2	1	3	4
(c) 4	1	3	2
(d) 2	3	1	4

46. The output of a linear system for step input is, $t^2 e^{-2t}$. Then the transfer function is

- (a) $\frac{s}{(s+1)^2}$ (b) $\frac{2s}{(s+1)^3}$
(c) $\frac{s}{s^2(s+1)}$ (d) $\frac{1}{(s+1)^3}$

47. In a three element Yagi antenna.

- (a) All the three elements are of equal length.
(b) The driven element and the director are of equal length but the reflector is longer than both of them.
(c) The reflector is longer than the driven element which in turn is longer than the director.
(d) The reflector is longer than the driven element which in turn is longer than the reflector.

48. Consider the following statements regarding depth of penetration or skin depth in a conductor:

- It increases as frequency increases.
- It is inversely proportional to square root of μ and σ .
- It is inversely proportional to square root of f .
- It is directly proportional to square root of μ and σ .

Which of the above statements are correct?

- (a) 1 and 2 only (b) 3 and 4 only
(c) 2 and 3 only (d) 1, 2, 3 and 4

49. Consider the following statements regarding depth of penetration of skin depth in a conductor:

- Both make the solution of circuit problems easy.
- Both are applicable for the study of circuit behaviour for $t \rightarrow \infty$ to a .
- Both convert differential equations to algebraic equations.
- Both can be used for transient and steady state analysis.

Which of the above statements are correct?

- (a) 1, 2, 3 and 4 (b) 2, 3 and 4 only
(c) 1, 2 and 4 only (d) 1, 3 and 4 only

50. The mode with lowest cutoff frequency for an electromagnetic wave propagating between two perfectly conducting parallel plates of infinite extent is

- (a) TE_{10} (b) TM_{10}
(c) TM_{01} (d) TEM

51. Encoder

- (a) Assigns quantized values.
(b) Changes quantized values to numerical values.
(c) Changes quantized values to numerical values.
(d) Changes numerical values to binary values.

52. Consider the following statements:

- (Electric or magnetic) field must have two orthogonal linear components.
- The two components must have the same magnitude.
- The two components must have a time-phase difference of odd multiples of 90° .

Which of these are the necessary and sufficient conditions for a time-harmonic wave to be circularly polarized at a given point in space?

- (a) 1 and 2 only (b) 2 and 3 only
(c) 1, 2 and 3 (d) 1 and 3 only

53. If the response of LTI continuous time system to unit step input

is $\frac{1}{2} - \frac{1}{2}e^{-2t}$, then impulse response of the system is

- (a) $\frac{1}{2} - \frac{1}{2}e^{-2t}$ (b) (e^{-2t}) ,
(c) $(1 - e^{-2t})$ (d) Constant

54. Consider the following statements regarding Thermistor:

1. It has a high sensitivity.
2. It has a linear relationship with temperature.
3. It is a resistive device.
4. It can be used as a time-delay device.

Which of the above statements are correct?

- (a) 1, 2, 3 and 4 (b) 2, 3 and 4 only
(c) 1, 3, and 4 only (d) 1, 2, and 3 only

55. In cylindrical waveguides, the attenuation will be minimum at a frequency which is $\sqrt{3}$ times the cut-off frequency modes of operations:

1. TE_{10}
2. TM_{11}
3. TM_{10}
4. TE_{11}

Which of the above are correct?

- (a) 1, 2, 3 and 4 (b) 2 and 3 only
(c) 1 and 2 only (d) 3 and 4 only

56. In a junction transistor, recombination of electrons and holes occurs in

- (a) Base region only (b) Emitter region only
(c) Collection region only (d) All the 3 regions

57. Given a range of frequencies, which of the following systems is best for transmission line load matching?

- (a) Single stub
(b) Double stub
(c) Single stub with adjustable position
(d) Quarter wave transformer

58. An axial magnetic field is applied to a cylindrical rod. The Faraday rotation of a plane polarized beam after emergence from the rod is 5° . If both the field and length of the rod are doubled, then the angle of rotation is

- (a) 40° (b) 5°
(c) 10° (d) 20°

59. Consider the following statement relating to the cavity resonator:

1. The cavity **resonator** does not possess as many modes as the corresponding waveguide does.
2. The resonant frequencies of cavities are very closely spaced.
3. The resonant frequency of a cavity **resonator** can be changed by altering its dimensions.

Which of the above statements is/are correct?

- (a) 2 and 3 only (b) 2 only
(c) 3 only (d) 1, 2 and 3

60. Consider the following statements:

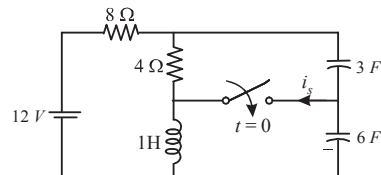
For a rectangular waveguide with dimensions $a \times b$ where b is the narrow dimension, small value of b

1. Gives a larger separation between cutoff frequencies of TE_{01} and TE_{10} modes.
2. Gives increased attenuation.
3. Limits power handling capabilities because of breakdown field limits.

Which of the above statements is/are correct?

- (a) 1 and 2 only (b) 1, 2 and 3
(c) 2 only (d) 3 only

61.



In the circuit shown above, the switch is closed after a long time. The current $i_s(0^+)$ through the switch is

- (a) 1 A (b) $2/3$ A
(c) $1/3$ A (d) 0 A

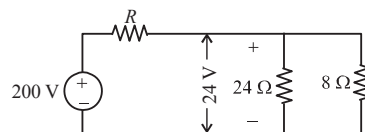
62. If a random process $X(t)$ is ergodic then, statistical averages

- (a) and time averages are different
(b) and time averages are same
(c) are greater than time averages
(d) are smaller than time averages

63. The correct statement is

- (a) Microstrip lines can support pure TEM mode of propagation but shielded coaxial lines cannot.
(b) Microstrip lines cannot support pure TEM mode of propagation but shielded coaxial lines can.
(c) Both microstrip lines and shielded coaxial lines can support pure TEM mode of propagation.
(d) Neither microstrip lines nor shielded coaxial lines can support pure TEM mode of propagation.

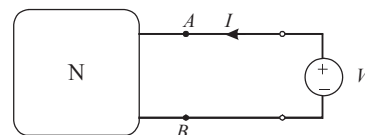
64.



The value of R in the above circuit is

- (a) 4Ω (b) 40Ω
(c) 44Ω (d) 440Ω

65.



For the network shown above

$I = (0.2 V - 2) A$, (I = the current delivered by the voltage source V). The thevenin voltage V_{th} and resistance R_{th} for the network N across the terminals AB are respectively.

- (a) $-10V, 5\Omega$ (b) $10V, 5\Omega$
(c) $-10V, 0.2\Omega$ (d) $10V, 0.2\Omega$

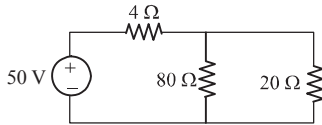
66. Z and Laplace transform are related by

- (a) $s = \ln z$ (b) $s = \frac{\ln z}{T}$
(c) $s = z$ (d) $s = \frac{T}{\ln z}$

67. A line of characteristic impedance 50 ohm is terminated at one end by $+j50$ ohms. The VSWR on the line is

- (a) 1 (b) ∞
(c) 0 (d) j

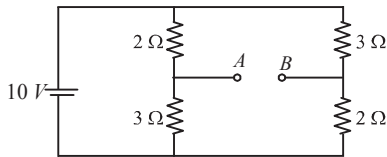
68.



The value of current in 80 Ω resistor of above circuit is

- (a) 0.5 A (b) 2.0 A
(c) 5.0 A (d) 20.0 A

69.



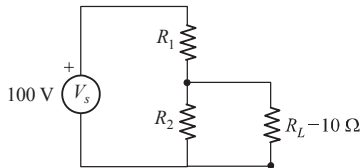
Thevenin equivalent voltage V_{AB} and resistance R_t across the terminals AB in the above circuit are

- (a) $6V, 5\Omega$ (b) $4V, 5\Omega$
(c) $2V, 2.4\Omega$ (d) $2V, 2.5\Omega$

70. Alumina is a

- (a) Dielectric (b) Ceramic
(c) Semiconductor (d) Conductor

71.



What is the voltage across the load resistance, R_L in the above circuit? The value of each resistor connected in the circuit is 10Ω

- (a) 3.33 V (b) 33.33 V
(c) 333.33V (d) 0 V

72. At UHF short-circuited lossless transmission lines can be used to provide appropriate values of impedance. Match list I with list II and select the correct answer using the code given below the lists:

List I

- (a) $l < \lambda/4$
(b) $l < \lambda/4 < l < \lambda/2$
(c) $l = \lambda/4$
(d) $l = \lambda/2$

List II

- (a) Capacitive
(b) Inductive
(c) 0
(d) ∞

Codes:

A	B	C	D
(a) 2	1	4	3
(b) 3	1	4	2
(c) 2	4	1	3
(d) 3	4	1	2

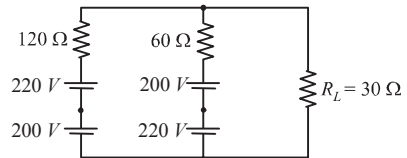
73. Convolution of two sequences $X_1[n]$ and $X_2[n]$ is represented as

- (a) $X_1(z) * X_2(z)$ (b) $X_1(z)X_2(z)$
(c) $X_1(z) + X_2(z)$ (d) $X_1(z)/X_2(z)$

74. A half-wave dipole working at 100 MHz in free space radiates a power of 1000 Watts. The field strength at a distance of 10 km in the direction of maximum radiation is

- (a) 1.73 mV/m (b) 2.12 mV/m
(c) 2.22 mV/m (d) 22.2 mV/m

75.



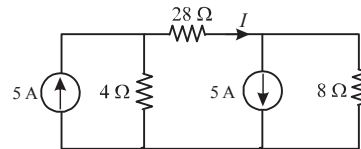
In the circuit shown above, the current through R_L is

- (a) 6 A (b) 4 A
(c) $2 A X_p[n]$ (d) 0

76. Decimation is the process of

- (a) Retaining sequence values of $X_p[n]$ other than zeroes.
(b) Retaining all sequence values of $X_p[n]$
(c) Dividing the sequence value of 10
(d) Multiplying the sequence value by 10

77.



In the circuit shown above, the current I is

- (a) 1 A (b) 1.5 A
(c) 2.5 A (d) 4 A

78. It is required to find the current through a particular branch of a linear bilateral network without mutual coupling when the branch impedance takes four different values. Which one of the following method will be preferred?

- (a) Mesh analysis
(b) Thevenin's equivalent circuit
(c) Nodal analysis
(d) Superposition theorem

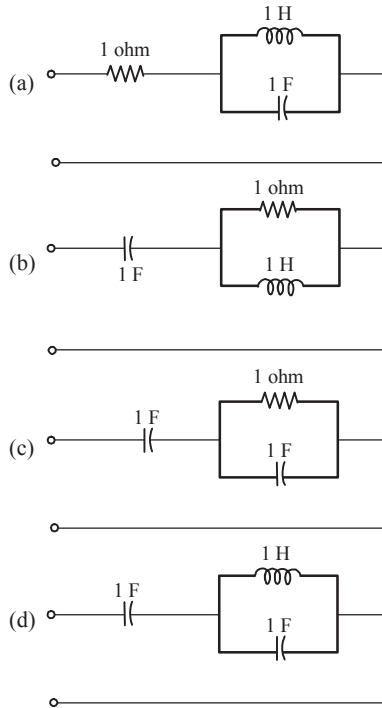
79. A source having internal impedance of $(9 + j2) \Omega$ is to deliver maximum power to a resistive load. The load resistance should be

(a) 9Ω (b) 12Ω
(c) 15Ω (d) 21Ω

80. There are two conducting plates of sizes $1 m \times 1 m$. Ratio of the capacitance of the second one with respect to that of the first one is

(a) 4 (b) 2
(c) $1/2$ (d) $1/4$

81. The driving point impedance of a network is given by $Z(s) = \frac{2s+1}{s(s+1)}$. The Foster realization of the network is



82. An air-filled rectangular waveguide has dimensions of $a = 6$ cm and $b = 4$ cm. The signal frequency is 3 GHz. Match list I with list II and select the correct answer using the codes given below the lists:

List I

(a) TE_{11}
(b) TE_{01}
(c) TE_{11}
(d) TM_{11}

List II

(a) 2.5 GHz
(b) 3.75 GHz
(c) 4.506 GHz
(d) 4.506 GHz

Codes:

A	B	C	D
(a) 1	2	3	4
(b) 4	2	3	1
(c) 1	3	2	4
(d) 4	3	2	1

83. If $X(\omega) = \delta(\omega - \omega_0)$ then $X(t)$ is

(a) $e^{-j\omega_0 t}$ (b) $\delta(t)$
(c) $\frac{1}{2\pi} e^{-j\omega_0 t}$ (d) 1

84. An electric charge of Q coulombs is located at the origin. Consider electric potential V and electric field intensity E at any point (x, y, z) .

Then

(a) E and V are both scalars.
(b) E and V are both vector.
(c) E is a scalar and V is a vector.
(d) E is a vector and V is a scalar.

85. Consider the following statements regarding a transmission line:

- Its attenuation is constant and is independent of frequency.
- Its attenuation varies linearly with frequency.
- Its phase shift varies linearly with frequency.
- Its phase shift is constant and is independent of frequency.

Which of the above statements are correct for distortionless line?

(a) 1, 2, 3 and 4 (b) 2 and 3 only
(c) 1 and 3 only (d) 3 and 4 only

86. Match list I with list II and select the correct answer using the code given below the lists:

List I

(Transducers)

(a) L. V. D. T.
(b) Strain Gauge
(c) Dielectric
(d) Thermocouple

List II

(Type of Transducers)

(a) Resistive
(b) Inductive
(c) Capacitive
(d) Self generating

Codes:

A	B	C	D
(a) 2	3	1	4
(b) 4	3	1	2
(c) 2	1	3	4
(d) 4	1	3	2

87. Consider the following:

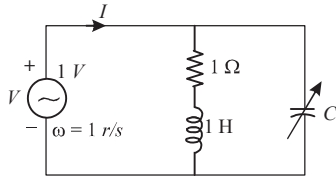
In a parallel plate capacitor, let the charge be held constant while the dielectric material is replaced by a different dielectric. Consider

- Stored energy.
- Electric field intensity.
- Capacitance.

Which of these changes?

(a) 1 only
(b) 1 and 2 only
(c) 2 and 3 only
(d) 1, 2 and 3

88.



In the above circuit, the value of C for the circuit to exhibit a power factor of 0.86 is approximately.

- (a) 0.4 F (b) 0.6 F
(c) 1.4 F (d) 0.1 F

89. A long straight non-magnetic conductor of radius 8 mm is carrying a uniform current density of 100 kA/m^2 in the a_z direction. For this case, which one of the following is not correct?

- (a) $\nabla \times H = 10^5 a_z \text{ A/m}^2$ for $0 < \rho < 8 \text{ mm}$
(b) $\nabla \times B = 0$
(c) The magnetic field intensity for $\rho > 8 \text{ mm}$ is $\frac{10^5}{2} \rho a_\phi \text{ A/m}$.
(d) The total current carried by the conductor is $6.4 \pi \text{ A}$

90. Consider the following statements:

They are given as necessary conditions for driving point functions with common factors in $p(s)$ and $q(s)$ cancelled:

- (a) The coefficients of the polynomial in $p(s)$ and $q(s)$ must be real.
(b) Poles and zeroes must be conjugate pairs if imaginary or complex.
(c) The terms of lowest degree in $p(s)$ and $q(s)$ may differ in degree by only at most.

91. For distortionless transmission through LTI system phase of $H(\omega)$ is

- (a) Constant (b) One
(c) Zero (d) Linearly dependent on ω .

92. Consider the following statements:

- The coefficients in the polynomials $p(s)$ and $q(s)$ must be real and positive.
- Poles and zeroes of $z(s)$ must be conjugate if imaginary or complex.

Which of these statements are associated with the driving point function $Z(s) = \frac{p(s)}{q(s)}$?

- (a) Both 1 and 2 (b) 1 only
(c) 2 only (d) Neither 1 nor 2

93. Consider the following statements relating to the electrostatic and magnetostatic fields:

- The relative distribution of charge on an isolated conducting body is dependent on the total charge of the body.
- The magnetic flux through any closed surface is zero.

Which of the above statements is/are correct?

- (a) Neither 1 nor 2 (b) 1 only
(c) 2 only (d) Both 1 and 2

94. The crystal in which atoms are chemically highly inactive and they do not form compounds with other atoms is

- (a) Ionic crystal (b) Metal
(c) Valence crystal (d) Van der Waals crystal

95. A two-port network has the ABCD parameters $\begin{matrix} -7 & 8 \\ 3 & 4 \end{matrix}$. Two

such identical networks are cascaded. The ABCD parameters of the overall cascaded network will be.

- (a) $\begin{matrix} -14 & 16 \\ 6 & 8 \end{matrix}$ (b) $\begin{matrix} -73 & 88 \\ 33 & 40 \end{matrix}$
(c) $\begin{matrix} -1 & 1 \\ 1 & 1 \end{matrix}$ (d) $\begin{matrix} -49 & 64 \\ 9 & 16 \end{matrix}$

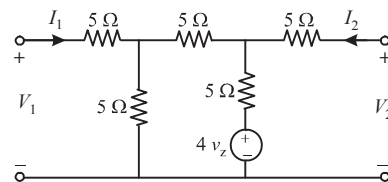
96. A circuit consists of two clocked JK flip-flops connected as follows: $J_0 = K_0 = \overline{Q_1}$, $J_1 = Q_0$ and $K_1 = \overline{Q_0}$. Each flip-flop receives the clock input simultaneously. The circuit acts as a

- (a) Counter of mod 3 (b) Counter of mod
(c) Shift-left register (d) Shift-right register

97. Which one of the following is not a ferromagnetic material?

- (a) Cobalt (b) Iron
(c) Nickel (d) Bismuth

98.



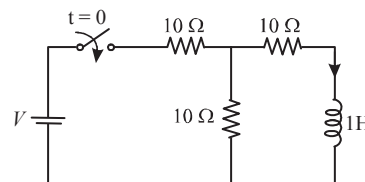
With reference to the above network the value of Z_{11} will be

- (a) -3 (b) 3
(c) -1 (d) -5

99. When donor atoms are added to semiconductor, it

- (a) Increases the energy band gap of the semiconductor.
(b) Decreases the energy band gap of the semiconductor.
(c) Introduces a new narrow band gap near the conduction band.
(d) Introduces a new discrete energy level below the conduction band.

100.



The value of V that would result in a steady-state current of 1 A through the inductor in the above circuit is

- (a) 30 V (b) 15 V
(c) 20 V (d) 25 V

ANSWER KEYS

1. (a)	2. (c)	3. (c)	4. (d)	5. (a)	6. (c)	7. (c)	8. (d)	9. (a)	10. (a)
11. (a)	12. (b)	13. (c)	14. (b)	15. (d)	16. (a)	17. (a)	18. (a)	19. (b)	20. (c)
21. (a)	22. (c)	23. (b)	24. (d)	25. (d)	26. (d)	27. (b)	28. (c)	29. (a)	30. (b)
31. (c)	32. (a)	33. (d)	34. (c)	35. (a)	36. (d)	37. (b)	38. (d)	39. (c)	40. (c)
41. (b)	42. (a)	43. (a)	44. (b)	45. (d)	46. (b)	47. (c)	48. (c)	49. (c)	50. (d)
51. (b)	52. (d)	53. (b)	54. (c)	55. (d)	56. (d)	57. (d)	58. (c)	59. (c)	60. (b)
61. (b)	62. (b)	63. (b)	64. (c)	65. (b)	66. (b)	67. (b)	68. (a)	69. (c)	70. (d)
71. (b)	72. (a)	73. (b)	74. (c)	75. (a)	76. (a)	77. (b)	78. (c)	79. (c)	80. (a)
81. (c)	82. (a)	83. (c)	84. (d)	85. (c)	86. (a)	87. (d)	88. (a)	89. (a)	90. (a)
91. (d)	92. (a)	93. (c)	94. (d)	95. (b)	96. (a)	97. (d)	98. (d)	99. (d)	100. (a)

TEST PAPER 8

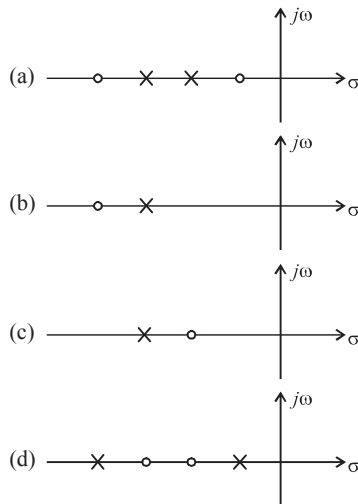
1. Consider the following applications:

1. Wind tunnel simulation
2. Real-time video viewing

A computer is used for

- (a) Neither 1 nor 2 (b) Both 1 and 2
(c) 1 only (d) 2 only

2. Which one of the following represent the pole-zero location in s-plane for lead compensator?



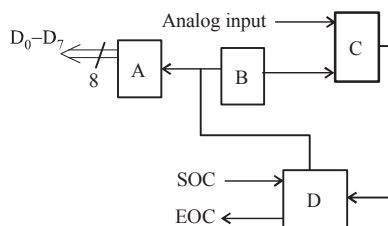
3. A 10 bit A/D converter is used to digitize an analog signal in the 0 to 5 V range. The maximum peak to peak ripple voltage that can be allowed in the DC supply voltage is, nearly:

- (a) 100 mV (b) 50 mV
(c) 25 mV (d) 5.0 mV

4. The trans function $G(s) = \frac{10}{(3s + 1)}$ has a corner frequency at:

- (a) 3 rad/s (b) 0.33 rad/s
(c) 1 rad/s (d) 1 rad/s

5.



Consider the above block diagram of a successive approximation A/D converter. Match list I with list II and select the correct answer using the code given below the lists:

List I
(Block)

- A.
B.
C.

D.

Codes:

A	B	C	D
(a) 4	1	2	3
(b) 3	1	2	4
(c) 4	2	1	3
(d) 3	2	1	4

List II
(Name)

1. Comparator
2. D/A converter
3. Successive approximations register
4. Output port

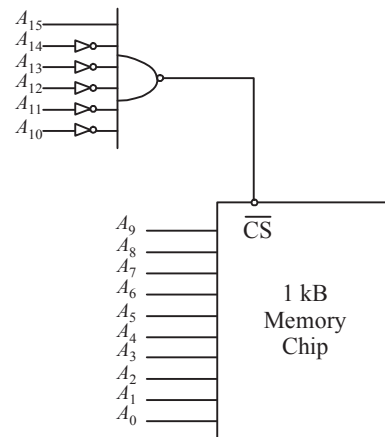
6. The purpose of a start bit in Rs232 serial communication protocol is:

- (a) To synchronize receiver for receiving every byte
(b) To synchronize receiver for receiving sequence of byte
(c) As a parity bit
(d) To synchronize receiver for receiving the last byte

7. The output stage of a transponder onboard a satellite has a maximum power output of 10 watts. However, it is not operated at the maximum power output in order to

- (a) Conserve the available limited battery power
(b) Reduce noise due to devices
(c) Avoid intermodulation distortion
(d) Avoid heating up of the satellite beyond a pre set value

8.



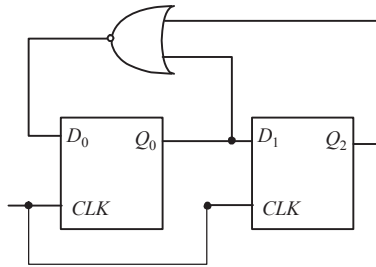
Consider a memory chip will 1024 bytes storage connected to a 8085 chip address lines (or any microprocessor with 16 address lines) as above. What is the range of memory address?

- (a) 0000 H to 03 FFFH (b) 1000 H to 13 FFH
(c) F000 H to F3 FFFH (d) 0000 H to FFFFH

9. From the point of view of stability and response speed of a closed loop system, the appropriate range for the value of damping ratio lies between:

(a) 0 to 0.2 (b) 0.4 to 0.7
(c) 0.8 to 1.0 (d) 1.1 to 1.5

10. For the circuit shown, the counter state ($Q_1 Q_0$) follows the sequence:

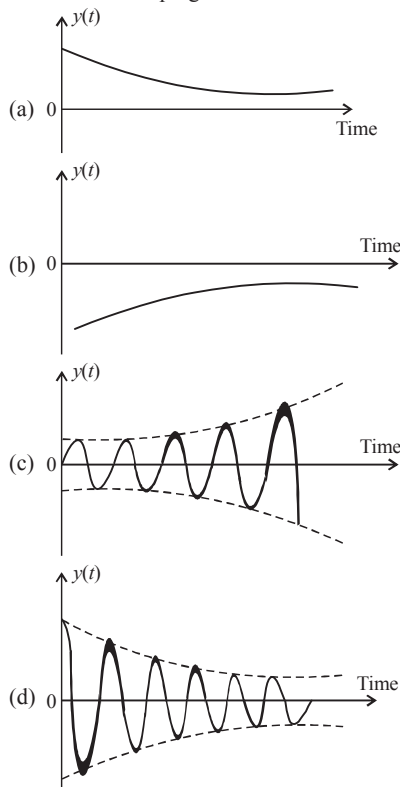


(a) 00, 01, 10, 11, 00... (b) 00, 01, 10, 11, 11...
(c) 00, 01, 11, 00, 00... (d) 00, 01, 10, 11, 11...

11. The output data lines of microprocessors and memories are usually tristated, because:

(a) More than one device can transmit information over the data bus by enabling only one device at a time
(b) More than one device can transmit information over the data bus at the same time
(c) The data lines can be multiplexed for both input and output
(d) It increases the speed of data transfers over the data bus

12. Which of the following the response of a spring-mass-damper with under-damping?



13. In a typical satellite communication system, which of the following could be the up-link and down-link frequency respectively?

(a) 40 GHz and 60 GHz (b) 60 GHz and 40 GHz
(c) 6 GHz and 4 GHz (d) 4 GHz and 6 GHz

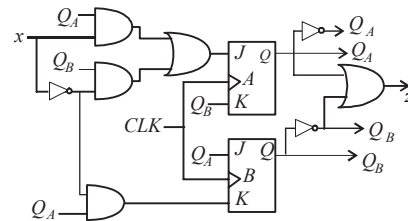
14. The magnitude and phase of the transfer function $G(s) = \frac{1}{s+1}$ at $\omega = 1$ is:

(a) 0.707 and 45° (b) -3 dB and 0.78 rad
(c) 0.707 and -45° (d) 3 dB and -90°

15. Which of the following instruction copies a byte of data into the accumulator from the memory address given in the instruction?

(a) LDA address (b) LDAX B
(c) LHLD address (d) STA address

- 16.



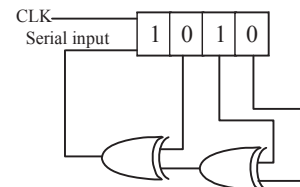
Analyse the sequential circuit shown above in figure. Assuming that initial state is 00, determine what input sequence would lead to state 11.

(a) 1 – 1 (b) 1 – 0
(c) 0 – 0 (d) State 11 is unreachable

17. A microprocessor based system can perform many different functions, because:

(a) Its operation is controlled by software
(b) It is digital system
(c) It uses a RAM
(d) It can be controlled by input and output devices

- 18.



The shift register shown in figure is initial loaded with the bit pattern 1010. Subsequently the shift register is clocked, and with each clock pulse the pattern gets shifted by one bit position to the right. With each shift, the bit at the serial input is pushed to the msb position. After how many clock pulses will the content of the shift register pulses will the content of the shift register become 1010 again?

(a) 3 (b) 7
(c) 11 (d) 15

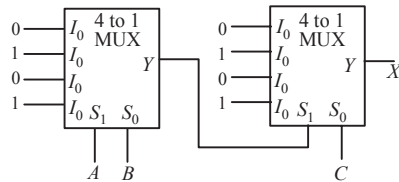
19. The interface chip used for data transmission between 8086 and a 16 bit ADC is:

- (a) 8251 (b) 8253
(c) 8355 (d) 8259

20. The Z-transform of $u(-n-1)$

- (a) $\frac{Z}{Z-1}$ with $|Z| > 1$ (b) $\frac{Z}{Z-1}$ with $0 < |Z| < 1$
(c) $\frac{Z}{Z-1}$ with $|Z| = 1$ (d) $\frac{Z}{Z-1}$ with $|Z| = 0$

21. In the below circuit, X is given by



- (a) $X = A \bar{B} \bar{C} + \bar{A} B \bar{C} + \bar{A} B C + ABC$
(b) $X = \bar{A} B C + A \bar{B} C + A B C + \bar{A} B C$
(c) $X = AB + \bar{B}C + AC$
(d) $X = \bar{A}B + \bar{B}C + AC$

22. A ROM is used to store the table for multiplication of two 8-bit unsigned integers. The size of the ROM required is

- (a) 256×1 (b) $64 k \times 8$
(c) $4 k \times 16$ (d) $64 k \times 16$

23. When compared with an RS232C serial port, the USB (Universal Serial Bus):

- (a) Supports a lower range of peripherals
(b) Supports a faster transfer rate
(c) Does not supports 'Hot plug-ability'
(d) Controller in PC can not detect the presence of USB devices

24. The Nyquist plot of loop transfer function $G(s)H(s)$ of a closed loop control system passes through the point $(-1, j0)$ in the $G(s)H(s)$ plane. The phase margin of the system is:

- (a) 0° (b) 45°
(c) 90° (d) 180°

25. Match list I with list II and select the correct answer using the code given below the lists:

List I

- A. Cavity wave meter
B. VSWR meter
C. Bolometer
D. Fraunhofer region

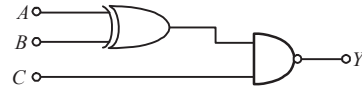
List II

1. Impedance measurement
2. Frequency measurement
3. Antenna measurement
4. Microwave power measurements

Codes:

A	B	C	D
(a) 3	1	4	2
(b) 2	1	4	3
(c) 3	4	1	2
(d) 2	4	1	3

26. The Boolean expression for the output of the below logic circuit is

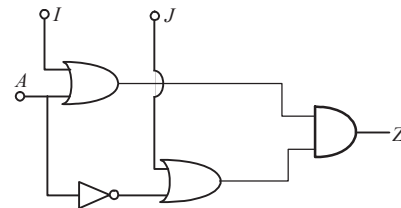


- (a) $Y = \bar{A}\bar{B} + AB + \bar{C}$ (b) $Y = \bar{A}B + A\bar{B} + \bar{C}$
(c) $Y = A + B + \bar{C}$ (d) $Y = AB + \bar{C}$

27. In the Bode plot of a unity feedback control system, the value of phase angle of $G(j\omega)$ is -90° at tie gain cross over frequency of the Bode plot, the phase margin of the system is:

- (a) -180° (b) $+180^\circ$
(c) -90° (d) $+90^\circ$

28. The circuit shown below is to be used to implement the function $Z = f(A, B) = \bar{A} + B$. The values of I and J are:



- (a) $I = 0$ and $J = B$ (b) $I = 1$ and $J = B$
(c) $I = B$ and $J = 1$ (d) $I = B$ and $J = 0$

29. Consider the following statements:

- The lock range of a PLL is the difference between the highest and lowest frequencies that the PLL can remain in lock onto.
- The capture range of a PLL is the range of frequencies that the voltage controlled oscillator of a PLL can produce.
- PLL can be used to synchronize the horizontal and vertical oscillators of TV receivers to incoming sync pulses

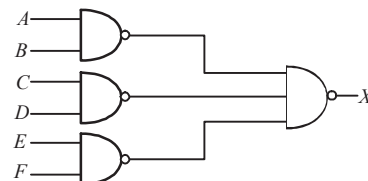
Which of the above statements is/are correct?

- (a) 1 only (b) 3 only
(c) 1 and 3 only (d) 1, 2 and 3

30. The 'Double minimum' or the "Width of minimum power" method is used in microwave measurements for the measurement of

- (a) Velocity modulation (b) Frequency distortion
(c) High V.S.W.R (d) Low V.S.W.R

31. The output X of the below logic circuit is:



- (a) $AB + CD + EF$
(b) $\bar{A}\bar{B} + \bar{C}\bar{D} + \bar{E}\bar{F}$
(c) $(A+B)(C+D)(E+F)$
(d) $(\bar{A}+\bar{B})(\bar{C}+\bar{D})(\bar{E}+\bar{F})$

32. If the CALL instruction of 8085 in the main program is conditional then RETURN instruction in the subroutine can be:
- Conditional
 - Conditional or unconditional
 - Can be determined by LDA instruction
 - Unconditional

33. A D/A converter has 5 V full-scale output voltage and an accuracy of $\pm 0.2\%$. The maximum error for any output voltage will be:

- 5 mV
- 10 mV
- 20 mV
- 1.0 mV

34. Consider the following instruction of 8085 microprocessor
The correct sequence in the decreasing order of their respective memory space requirement is:

- MOV B, C
- STA address
- ORI byte

The correct sequence in the decreasing order of their respective memory space requirement is:

- 3, 2 and 1
- 1, 3 and 2
- 1, 2 and 3
- 2, 3 and 1

35. Which one of the following is a Dirichlet condition?

- $\int_{t_1}^{\infty} |x(t)| < \infty$
- Signal $x(t)$ must have a finite number of maxima and minima in the expansion interval
- $x(t)$ can have an infinite number of finite discontinuities in the expansion interval
- $x^2(t)$ must be absolutely summable

36. An example of a spooled device is:

- A graphical display device
- A line printer used to print the output of a number of jobs
- A secondary storage device in a virtual memory system
- A terminal used to enter input data to a running program

37. A TDM system is to be designed to multiplex the following two signals:

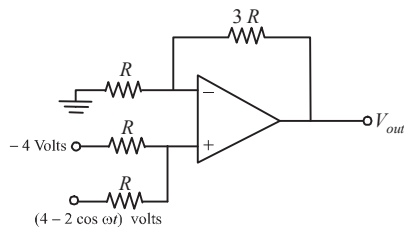
$$x_1 = 5 \cos(2000\pi t)$$

$$x_2 = 2 \cos(2000\pi t) \cos(3000\pi t)$$

The minimum sampling rate is:

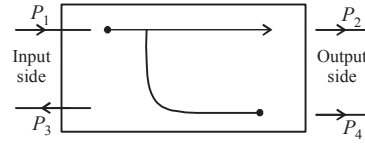
- 4 kHz
- 5 kHz
- 10 kHz
- 6 kHz

38. The output of the below OP-amp circuit is



- 0.75 volts
- 2 cos ω volts
- 8 cos ωt volts
- 16 volts

39. For the below directional coupler, a coupling factor in dB is:



- $10 \log_{10} \frac{P_1}{P_4}$
- $10 \log_{10} \frac{P_1}{P_2}$
- $10 \log_{10} \frac{P_2}{P_4}$
- $10 \log_{10} \frac{P_1}{P_3}$

40. Match List I with List II and select the correct answer using the code given below the lists:

List I

- Pipelined ALU
- Simpler compiler
- Separate data and Instruction caches
- Lesser cycles per Instruction

List II

- RISC
- CISC
- Mixed RISC-CISC

Codes:

A	B	C	D
(a) 3	2	3	1
(b) 1	2	3	3
(c) 3	3	2	1
(d) 3	3	3	1

41. A rectifier (without filter) with fundamental ripple frequency equal to twice the mains frequency, has ripple factor of 0.482 and power conversion efficiency equal to 81.2%. the rectifier is

- Bridge rectifier
- Full-wave (non bridge) rectifier
- Half-wave rectifier

Which of these are correct

- 2 and 3 only
- 2 only
- 1 and 3 only
- 1, 2 and 3

42. The ability to halt the CPU temporarily and use this interval of time to send information on buses is called:

- Cycle stealing
- Vectoring an interrupt
- Polling
- Direct memory access

43. In a unity feedback control system with $G(s) = \frac{4}{s^2 + 0.4s}$

when subjected to unit step input, it is required that system response should be settled within 2% tolerance band; the system settling time is

- 1 sec
- 2 sec
- 10 sec
- 20 sec

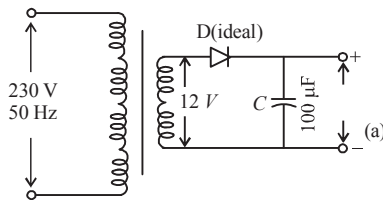
44. A single bus structure is primarily found in:

- Main frames
- Mini and micro computers
- Super computers
- High performance machines

45. The Boolean expression

$$\overline{A + \overline{B} + C} + \overline{\overline{A} + \overline{B} + C} + \overline{A + \overline{B} + \overline{C}} + ABC \text{ reduce to:}$$

- (a) A (b) B
(c) C (d) A + B + C
46. The number of edges in a regular graph of degree D and N vertices is equal to:
(a) ND (b) ND/2
(c) N + D (d) N^D
47. A transistor works in three regions:
1. Cut-off
2. Active
3. Saturation
While used as switch in digital logic gates, the regions it works in are:
(a) 1 and 2 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3
48. Which of the following data structure is used by a compiler to manage information about variables and their attributes?
(a) Abstract syntax tree (b) Linked list
(c) Parse table (d) Symbol table
49. The output V_{dc} from the below circuit is:



- (a) $12\sqrt{2}$ (b) $\frac{12}{\pi}$
(c) $\frac{24}{\pi}$ (d) $\frac{12}{\sqrt{2}}$
50. Match List I with List II and select the correct using the code given below the lists:
- | List I | | List II | |
|--------------------------|--------------------------|---------|--|
| A. Rectangular waveguide | 1. Plane of polarization | | |
| B. Waveguide twists | 2. Waveguide tuner | | |
| C. Slotted section | 3. TE ₁₀ mode | | |
| D. Stub screws | 4. VSWR measurements | | |
- Codes:**
- | A | B | C | D |
|-------|---|---|---|
| (a) 2 | 4 | 1 | 3 |
| (b) 3 | 4 | 1 | 2 |
| (c) 2 | 1 | 4 | 3 |
| (d) 3 | 1 | 4 | 2 |
51. The spectrum of a band pass signal spans from 20 kHz to 30 kHz. the signal can be recovered ideally from the sample values when the sampling rate is at least:
(a) 20 kHz (b) 60 kHz
(c) 50 kHz (d) 40 kHz
52. Insertion of a record in a circularly linked list involves the modification of
(a) 4 pointers (b) 3 pointers
(c) 2 pointers (d) 1 pointer

53. The data type defined by user is:
(a) Built-in data type
(b) Abstract data type
(c) Homogeneous data type
(d) Real data type
54. Consider the function $F(s) = \frac{5}{s(s^2 + 3s + 2)}$ where $F(s)$ is Laplace transform of function $f(t)$. The initial value of $f(t)$ is:
(a) 5 (b) $\frac{5}{2}$
(c) $\frac{5}{3}$ (d) 0
55. The default parameter-passing mechanism in C-programming language is:
(a) Call by reference (b) Call as random
(c) Call by reference (d) Call by value result
56. Match list I with list II and select the correct answer using the code given below the lists:
- | List I
(Device) | List II
(Application) |
|---------------------------------|-------------------------------------|
| A. Transferred electron devices | 1. Microwave amplifier |
| B. Two-cavity Klystron | 2. Microwave oscillator |
| C. PIN diode | 3. Microwave low power measurements |
| D. Bolometer | 4. Modulator |
- Codes:**
- | A | B | C | D |
|-------|---|---|---|
| (a) 4 | 1 | 2 | 3 |
| (b) 3 | 1 | 2 | 4 |
| (c) 4 | 2 | 1 | 3 |
| (d) 3 | 2 | 1 | 4 |
57. A 13 bit PCM system performance is better than an 8 bit PCM system because:
(a) Noise is lower and is proportional to reciprocal of bandwidth
(b) Bandwidth is larger and detection is easier
(c) Quantization noise is lesser other things being equal
(d) Quantization noise is nearly zero since 2¹³ levels are available
58. The hexadecimal representation of 657 is:
(a) 1AFH (b) D78H
(c) D71H (d) 32FH
59. A linear time-invariant system initially at rest, when subject to a unit-step input, gives a response v , $t > 0$. The transfer function of the system is:
(a) $\frac{1}{(s+1)^2}$ (b) $\frac{1}{s(s+1)^2}$
(c) $\frac{s}{(s+1)^2}$ (d) $\frac{1}{s+1}$

60. Consider the following statements:

When compared with a bridge rectifier, a centre-tapped full wave rectifier:

1. Has larger transformer utilization factor
2. Can be used for floating output terminal i.e., no input terminal is grounded.
3. Needs two diodes instead of four.
4. Needs diode of a lower PIV rating.

Which of the above statements are correct?

- (a) 1 and 2 only (b) 1, 2, 3 and 4
(c) 3 only (d) 3 and 4 only

61. Consider the following:

1. Compilers
2. Design
3. Evaluation
4. Instruction set architecture

Which of these are included in the present definition of computer architecture to design a full computer system?

- (a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2, 3 and 4

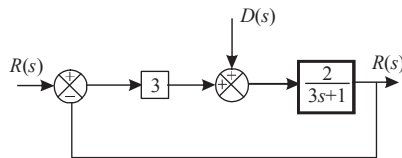
62. The Nyquist rate for the signal $x(t) = 2 \cos(2000\pi t) \cos(5000\pi t)$ is:

- (a) 7 kHz (b) 5 kHz
(c) 14 kHz (d) 10 kHz

63. Given that main memory access time is 1200 ns and Cache access time is 100 ns; the average memory access time is not to exceed 120 ns. The hit ratio for the Cache must be at least:

- (a) 90% (b) 98%
(c) 80% (d) 75%

64. The transfer function from $d(s)$ to $y(s)$ is:

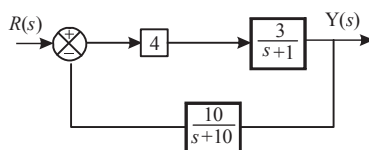


- (a) $\frac{2}{3s+7}$ (b) $\frac{2}{3s+1}$
(c) $\frac{6}{3s+7}$ (d) $\frac{2}{3s+6}$

65. An I/O processor controls the flow of information between:

- (a) Cache memory and I/O devices
- (b) Main memory and I/O devices
- (c) Two I/O devices
- (d) Cache and main memory

66. The characteristic equation of the below closed-loop system is



- (a) $s^2 + 11s + 10 = 0$ (b) $s^2 + 11s + 130 = 0$
(c) $s^2 + 10s + 120 = 0$ (d) $s^2 + 11s + 12 = 0$

67. The standard SOP expression for Boolean expression $A\bar{B} + AC + BC$ is:

- (a) $A\bar{B}C + \bar{A}BC + A\bar{B}\bar{C} + ABC$
(b) $AB\bar{C} + \bar{A}BC + ABC$
(c) $A\bar{B}C + AB\bar{C} + ABC$
(d) $\bar{A}\bar{B}C + AB\bar{C} + A\bar{B}\bar{C}$

68. The complement of the expression

$$Y = ABC + ABC\bar{C} + \bar{A}BC + \bar{A}\bar{B}C$$

- (a) $(A + \bar{B})(A + C)$ (b) $(\bar{A} + B)(A + C)$
(c) $(A + \bar{B})(A + C)$ (d) $(\bar{A} + \bar{B})(A + \bar{C})$

69. Which one of the following has the shortest access time?

- (a) NMOS EPROM (b) NMOS RAM
(c) CMOS RAM (d) Bipolar static RAM

70. The main disadvantage of using coaxial cable for microwave signals is its

- (a) Low selectivity (b) Low distortion
(c) High attenuation (d) High sensitivity

71. If the gain of the system is reduced to zero value, the roots of the system in the s-plane:

- (a) Coincide with zeros
(b) Move away from the zeros
(c) Move away from the poles
(d) Coincide with the poles

72. The figure of merit of a logic family is given by the product of

- (a) Gain and bandwidth
(b) Propagation delay time and power dissipation
(c) Fan-out and propagation delay time
(d) Noise margin and power dissipation

73. In NOR-NOR configuration, the minimum number of NOR gates needed to implement the switching function $X + XY\bar{Z} + X\bar{Y}Z$ is

- (a) 5 (b) 3
(c) 2 (d) 0

74. The addition of open loop zero pulls the root-loci towards:

- (a) The left and therefore system becomes more stable
(b) The right and therefore system becomes unstable
(c) Imaginary axis and therefore system becomes marginally stable
(d) The left and therefore system becomes unstable

75. Match list I with list II and select the correct answer using the code given below the lists:

List I

- A. HTL
B. CMOS
C. PL
D. ECL

List II

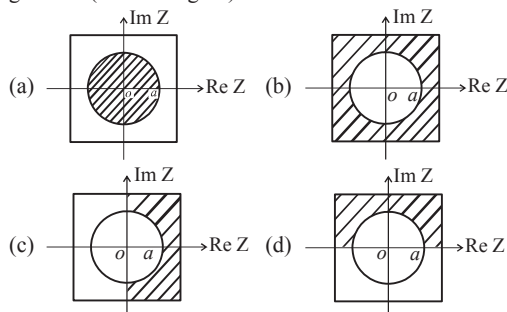
1. High fan-out
2. Highest speed of operation
3. High noise immunity
4. Lowest product of power and delay

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	3	1	2	4
(c)	4	2	1	3
(d)	3	2	1	4

76. On receiving an interrupt from an I/O device, the CPU
- Half for a predetermine time
 - Branches off to the interrupt service routine after completion of the current instruction
 - Branches off to the interrupt service routine
 - Hands over control of address bus and data bus to the interrupting device
77. Consider the following statements with regard to a PLL:
- The 'Capture range' of a PLL primarily depends upon the slope of transition band edge of the low pass filter.
 - The 'lock range' is not affected by the slope of transition band of the low-pass filter
- Which of the above statement is/are correct?
- Both 1 and 2
 - 1 only
 - 2 only
 - Neither 1 nor 2
78. In microprocessor based system, DMA facility is required to increases the speed of data transfer between the
- Microprocessor and the I/O devices
 - Microprocessor and the memory
 - and the I/O devices
 - Memory and the reliability system
79. If $x(t)$ is of finite duration and is absolutely integrable, then the 'region of convergence' is:
- Entire s plane
 - From $\sigma = -1$ to $\sigma = +\infty$
 - From $\sigma = +1$ to $\sigma = -\infty$
 - Entire right half plane
80. The quantization noise of a PCM system depends on
- Number of quantization levels
 - Step-size
 - Both step-size and number of quantization levels
 - Sampling rate

81. Given $X(z) = \frac{1}{1 - az^{-1}} |z| > |a|$ then the region of convergence is (Shaded region):



82. A 'DMA' transfer implies:
- Direct transfer of data between memory and accumulator
 - Direct transfer of data between memory and I/O devices without the use of μP
 - Transfer of data exclusively with μP register
 - A fast transfer of data between μP and I/O devices
83. Consider the below circuit, for $V_i = V_m \sin \omega t$, the output voltage V_o for $R_L \rightarrow \infty$ will be
- Zero
 - V_m
 - $2V_m$
 - v
84. For the Nichols plot shown, the system is
- Unstable
 - Stable
 - Overdepend
 - Critically stable
85. The 8085 has two registers known as primary data pointer. These are registers:
- B and C
 - D and E
 - H and L
 - C and D
86. The correct statements is
- PROM contains a programmable AND array and a fixed OR array
 - PLA contains a fixed AND array and a programmable OR array
 - PROM contains a fixed AND array and programmable OR array
 - PLA contains a programmable AND array and a fixed OR array
87. The circuit shown below is a:
- Bi-stable multi-vibrator
 - Mono-stable multi-vibrator
 - free running multi-vibrator
 - Ramp generator
88. Consider the following statements:
- A multiplexer is analogous to a rotary switch
 - A decoder is a combinational logic circuit that converts binary information from 'n' input lines to a maximum of 2^n distinct elements at the output.
 - The Boolean expression for the output difference 'D' from a full subtracter is exactly the same as the output sum 'S' from a full adder

Which of the above statements is/are correct?

- 2 and 3 only
- 3 only
- 1 and 3 only
- 1, 2 and 3

89. A ship to ship communication system is affected by fading. A useful solution which can be used is
- A more directional antenna
 - A broadband antenna
 - Use of frequency diversity
 - Use of space diversity
90. The impulse response $h[n]$ of an LTI system is
- $$h[n] = u[n+3] + u[n-2] - 2u[n-7]$$

Then the system is

1. Stable
 2. Casual
 3. Unstable
 4. Not casual
 - (a) 1 and 2 only
 - (b) 2 and 3 only
 - (c) 3 and 4 only
 - (d) 1 and 4 only
91. For the experimental study of small, microwave antennas, a free space environment with minimum interference by external objects, the facilities required are:
- (a) RF screens, VSWR meter, waveguide twist
 - (b) UHF screens, slotted waveguide
 - (c) Anechoic chamber, Network analyzer, Pattern recorder
 - (d) Dark room facility, Digital recorder Bolometer
92. READY signal in 8085 is useful when the CPU communicates with:
- (a) A slow peripheral devices
 - (b) A fast peripheral devices
 - (c) A DMA controller chip
 - (d) A PPI chip
93. A 4×1 MUX is used to implement a 3-input Boolean function is as shown below. the Boolean function $F(A, B, C)$ implemented is:
- (a) $F(A, B, C) = \sum (1, 2, 4, 6,)$
 - (b) $F(A, B, C) = \sum (1, 2, 6,)$
 - (c) $F(A, B, C) = \sum (2, 4, 5, 6,)$
 - (d) $F(A, B, C) = \sum (1, 5, 6)$
94. Population inversion in semiconductor laser diode is achieved by:
- (a) Lightly doping p and n sides
 - (b) Introducing trap centres on p and n sides
 - (c) Heavily doping p and n sides
 - (d) Reverse biasing the junction
95. In the following 8085 program, how many times (decimal) is the DCRC executed?

LOOP:

MVIC, 78 H

DCRC

NZ LOOP

HLT

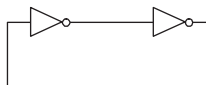
- (a) 119
 - (b) 120
 - (c) 78
 - (d) 77
96. Processing of MOS ICs is less expensive than bipolar ICs primarily because they:
- (a) Use cheaper components
 - (b) Need no component isolation
 - (c) Require much less diffusion steps
 - (d) Have very high packing density
97. The correct waveform for output V_o for the below network is
- (a)
 - (b)
 - (c)
 - (d)
98. The J-K flip-flop shown below is initially reset, so that $Q = 0$. If a sequence of four clock pulses is then applied, with the J and K inputs as given in the figure, the resulting sequence of values that appear at the output Q starting with its initial state, is given by
- (a) 01011
 - (b) 01010
 - (c) 00110
 - (d) 00101
99. A signal instruction to clear the lower four bits of the accumulator in 8085 assembly language is
- (a) XRI 0FH
 - (b) ANI F0H
 - (c) XRI F0H
 - (d) ANI 0FH
100. An X-Y flip-flop, whose characteristic table is given below is to be implemented using J-K flip-flop. This can be done by making
- (a) $J = X, K = \bar{Y}$
 - (b) $J = \bar{X}, K = Y$
 - (c) $J = X, K = \bar{X}$
 - (d) $J = \bar{Y}, K = X$

ANSWER KEYS

1. (c)	2. (c)	3. (b)	4. (b)	5. (c)	6. (a)	7. (a)	8. (b)	9. (b)	10. (b)
11. (a)	12. (b)	13. (c)	14. (c)	15. (a)	16. (c)	17. (a)	18. (b)	19. (c)	20. (b)
21. (a)	22. (d)	23. (b)	24. (a)	25. (b)	26. (a)	27. (d)	28. (b)	29. (d)	30. (c)
31. (a)	32. (b)	33. (d)	34. (b)	35. (b)	36. (b)	37. (b)	38. (b)	39. (a)	40. (c)
41. (c)	42. (d)	43. (b)	44. (d)	45. (b)	46. (a)	47. (c)	48. (d)	49. (b)	50. (d)
51. (a)	52. (c)	53. (b)	54. (d)	55. (c)	56. (b)	57. (d)	58. (a)	59. (c)	60. (c)
61. (c)	62. (a)	63. (b)	64. (a)	65. (b)	66. (b)	67. (a)	68. (d)	69. (d)	70. (c)
71. (d)	72. (b)	73. (d)	74. (a)	75. (c)	76. (b)	77. (a)	78. (c)	79. (a)	80. (c)
81. (b)	82. (b)	83. (c)	84. (b)	85. (c)	86. (c)	87. (b)	88. (c)	89. (c)	90. (d)
91. (b)	92. (a)	93. (a)	94. (b)	95. (c)	96. (d)	97. (a)	98. (d)	99. (b)	100. (d)

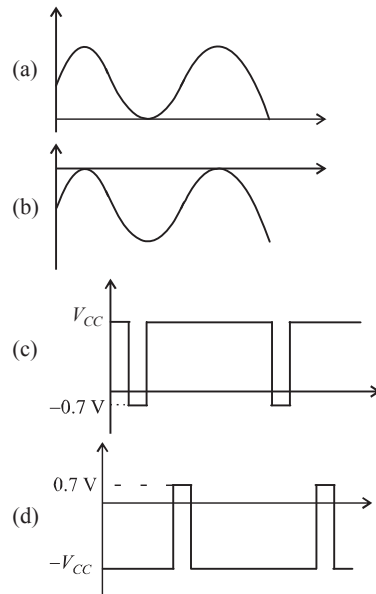
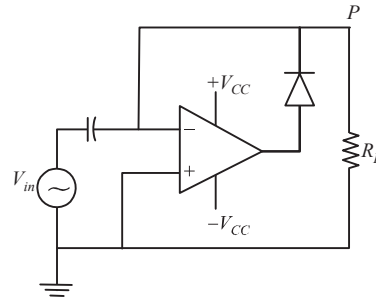
TEST PAPER 9

- On receiving an interrupt, the CPU of an 8085 microprocessor
 - Completes the current instruction and then goes to the interrupt service routine.
 - Branches off to the interrupt service routine immediately.
 - Hands over control of address bus and data bus to the interrupting device.
 - Goes to HALT state for pre-determined period.
- Which one of the following is **not** a characteristic of RTL logic families?
 - High switching speed
 - Poor noise immunity
 - Low power dissipation
 - Fan out is s
- For what value of damping parameter, the transient stability is assured by equal area criterion?
 - Independent of systems damping.
 - If only damping is exactly zero.
 - For all values of damping parameters.
 - If only damping is positive and finite.
- Armature reaction AT of a synchronous generator supplying power at rated voltage with zero power factor lagging is
 - Magnetizing
 - Demagnetizing
 - Cross-magnetizing
 - Both magnetizing and cross-magnetizing
- The digital circuit using two inverters as shown below acts as



- A bistable multivibrator
 - An astable multivibrator
 - A monostable multivibrator
 - An oscillator
- Power factor of an alternator driven by constant prime mover input can be changed its
 - Speed
 - Load
 - Field excitation
 - Phase sequence
 - Which of the following power stations is mainly used to cover peak load on the system?
 - Coal based thermal power plant
 - Nuclear power plant
 - Gas based thermal power plant
 - Pumped storage hydro power plant

- For the given sinusoidal input to the circuit as shown below. The voltage waveform at point 'p' of the clamper circuit is



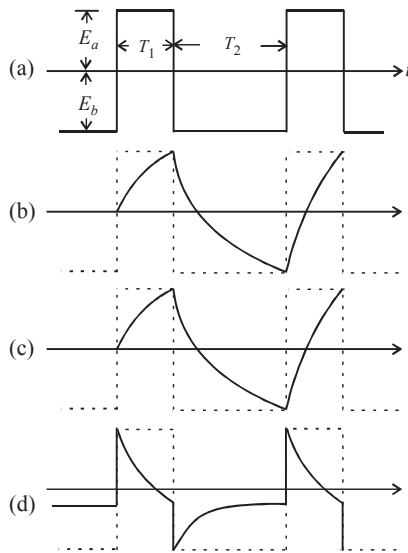
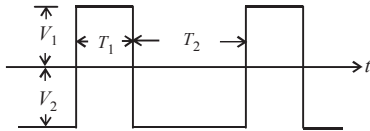
- A constant current source inverter supplies 20 A to a load resistance of 1 Ω . If the load resistance is changed to 5 Ω , then the load current
 - Remains same at 20 A where as the load voltage change to 100 V
 - Changes to 4 A from 20 A and the load voltage changes to 20 V
 - Changes to 4 A from 20 A and the load voltage changed to 80 V
 - And load voltage stay at 20 A and 20 V, respectively
- What is the assigned bandwidth of each of the channels in the AM broadcast band?

(a) 5 kHz	(b) 10 kHz
(c) 15 kHz	(d) 200 kHz
- A 3-phase, 11 kV, 5MVA alternator has synchronous reactance of 10 Ω per phase. Its excitation is such that the generated

e.m.f is 14 kV. If the alternator is connected to infinite bus bar, the maximum output at the given excitation is

- (a) 15,400 kW (b) 8,000 kW
(c) 6,200 kW (d) 5,135 kW

12. For low pass RC circuit the input waveform is as shown below. What will be the output waveform if the time constant of the circuit is equal to the time period of the input signal ($RC = T_1 + T_2$)?



13. Consider the following statement:

The armature torque in a DC motor is a function of

1. Field flux. 2. Armature current
3. Speed 4. Damping

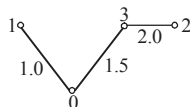
Which of the above statements is/are correct?

- (a) 1, 2, 3 and 4 (b) 3 and 4 only
(c) 1 and 2 only (d) 4 only

14. Sixty-four number of 256×1 bit RAM IC is arranged in 8 rows and 8 columns to get memory of

- (a) 1 kB (b) 2 kB
(c) 4 kB (d) 8 kB

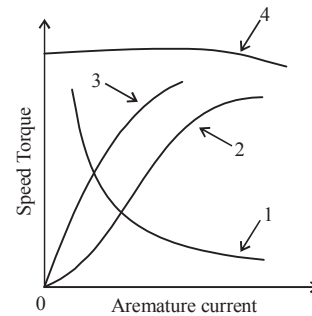
15. For a graph of power system network shown in figure below, where bus numbers and impedances are marked, assuming equal R/X of impedances, find the bus impedance matrix element Z_{22} .



- (a) 2.0 (b) 3.5
(c) 0.5 (d) 4.5

16. Consider the following statements:

In the below figure, the curves pertain to the DC motor.



- (a) Speed Vs armature-current characteristic of a DC shunt motor.
(b) Torque Vs armature-current characteristic of a DC shunt motor.
(c) Speed Vs armature-current characteristics of a DC series motor.
(d) Torque Vs armature-current characteristic of a DC series motor.

What is the correct sequence of characteristic?

Codes:

	A	B	C	D
(a)	4	1	3	2
(b)	2	1	3	4
(c)	4	3	1	2
(d)	2	3	1	4

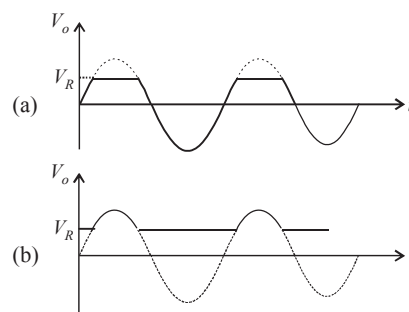
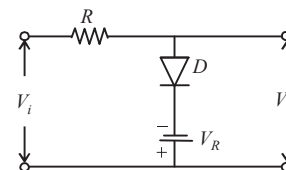
17. For a non-uniform quantizer more quantizing steps are used for singles of

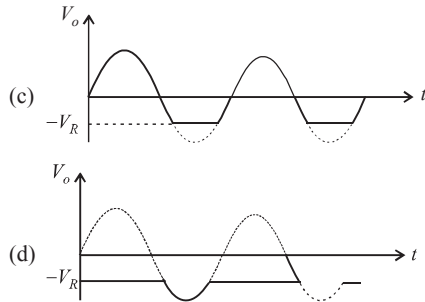
- (a) Low frequency (b) High amplitude
(c) Low amplitude (d) High frequency

18. The armature MMF waveform of a dc machine is

- (a) Pulsating (b) Rectangular
(c) Triangular (d) Sinusoidal

19. For sinusoidal input of peak value V_p , the output waveform V_o will be





20. Consider the following:

1. EMF
2. Reversal
3. MMP
4. Direct

Which methods among these are for the determination of voltage regulation of an alternator?

- (a) 1, 2, 3 and 4
- (b) 1 and 2 only
- (c) 2 and 3 only
- (d) 1 and 3 only

21. Three individual 3-phase 400 kV power systems, each one of which consists of a generator transformer and a radial line having 3- ϕ symmetrical fault level of 20 GVA for fault at the remote end of lines, are now reinforced by interconnecting the remote end lines by three lines each of reactance $j12$ so that the fault level at each remote end of the radial lines on ignoring resistance becomes

- (a) 10 GVA
- (b) (20/3) GVA
- (c) 24 GVA
- (d) 20 GVA

22. Handshaking mode of data transfer is

- (a) Synchronous data transfer
- (b) Asynchronous data transfer
- (c) Interrupt driven data transfer
- (d) Level mode of DMA data transfer

23. Match list I with list II and select the correct answer using the code given below the lists:

List I

- (a) Source encoder
- (b) Channel encoder
- (c) Line coder
- (d) Equalizer

List II

- (a) Reduce ISI
- (b) Synchronization
- (c) Message protection
- (d) Maximization of information transmitted

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	4	2	3	1
(c)	1	3	2	4
(d)	4	3	2	1

24. Consider the following statements:

When Darlington circuit and normal single stage emitter followers are compared

1. Both have near unity voltage gain.
2. Both have equal current gain.
3. Darlington circuit has higher output resistance.
4. Emitter following has lower input resistance.

Which of the above statements is/are correct?

- (a) 1 only
- (b) 1 and 4 only
- (c) 2 and 4 only
- (d) 1, 2, 3 and 4

25. Static VAR controllers are used to provide dynamic voltage regulation. These controllers are primarily of

- (a) Thyristor switched inductors
- (b) Thyristor controlled capacitors
- (c) Thyristor switched resistor switched capacitors
- (d) Thyristor controlled inductors and thyristor switched capacitors

26. For the parallel operation of transformers, which of the following conditions must be satisfied?

- (a) Same voltage ratios
- (b) Must be connected in proper polarities
- (c) R_e/X_e ratio should be the same
- (d) Same kVA rating

27. A 10 kVA, 400 V/200 V single-phase transformer with 10% impedance, draws a steady short circuit current of

- (a) 50 A
- (b) 150 A
- (c) 250 A
- (d) 350 A

28. The smallest valid signed integer that can be stored in a memory location of a $4k \times 8$ bit RAM is

- (a) 0
- (b) -128
- (c) -2048
- (d) -65536

29. Which one of the following statements is **incorrect** about the matched filter?

- (a) The maximum output SNR depends on the input signal energy.
- (b) The impulse response is reversed delayed version of the input signal.
- (c) The error probability depends on the wave shape of the signal.
- (d) Matched filter and correlator gives identical reception performances.

30. For a function F, the Karnaugh map is shown below. Then minimal representation of F is

		BC			
A	$\bar{A}$	$\bar{B}\bar{C}$	$\bar{B}C$	BC	$B\bar{C}$
	$\bar{A}$		1	1	1
A			1	1	

- (a) $AB + \bar{C}$
- (b) $C + \bar{A}B$
- (c) $A + B + C$
- (d) $A + \bar{B}C$

31. Consider the following devices:

1. Synchronous condenser
2. Saturable reactor
3. SCCR
4. FCCR

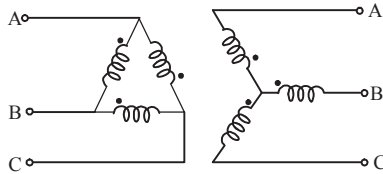
In which of these devices, the accuracy of compensation is very high and noise level is very low?

- (a) 1, 2, 3 and 4
- (b) 3 and 4 only
- (c) 3 only
- (d) 2 and 3 only

32. For a P-pole machine, the relation between electrical and mechanical degrees is

(a) $\theta_{\text{elec}} = \frac{2}{p} \theta_{\text{mech}}$ (b) $\theta_{\text{elec}} = \frac{4}{p} \theta_{\text{mech}}$
 (c) $\theta_{\text{elec}} = \theta_{\text{mech}}$ (d) $\theta_{\text{elec}} = \frac{p}{2} \theta_{\text{mech}}$

33. For ΔY transformer, connections and terminal markings are shown in the below figure. If 1 and 2 represents positive and negative sequence, then the correct solution in per unit values for V_{A_1} and V_{A_2} is



- (a) jV_{A_1} and $-jV_{A_2}$ (b) V_{A_1} and $-jV_{A_2}$
 (c) jV_{A_1} and $-V_{A_2}$ (d) V_{A_1} and $-V_{A_2}$

34. What will happen if a short circuit fault occurs in a switched capacitor controlled reactor?

- (a) Oscillation (b) Capacitor discharge
 (c) Over voltage (d) Noise

35. MVI A, AAH
 ORI FFH
 RRC
 RRC
 CMC
 INR A

What are the contents of A and PSW registers after executing the above set of instructions in sequence?

- (a) AAH and 00H (b) FFH and 66H
 (c) 00H and 54H (d) 00H and 00H

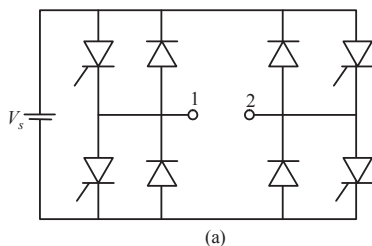
36. The input resistance R_i and output resistance R_o of an ideal current amplifier, in ohms, are

- (a) 0 and 0 (b) 0 and ∞
 (c) ∞ and 0 (d) ∞ and ∞

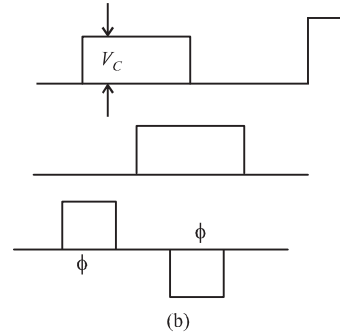
37. Which one of the following pulse communications systems is digital?

- (a) PAM (b) PCM
 (c) PPM (d) PWM

38. The below figure shows an inverter circuit with a dc source voltage V_s . The semiconductor switches of the inverter are operated in such a way that the pole voltage of V_{10} and V_{20} shown in the figure (b). What is the RMS value of the pole voltage V_{12} ?



(a)



(b)

- (a) $\frac{V_s \phi}{\sqrt{2\pi}}$ (b) $V_s \sqrt{\frac{\phi}{\pi}}$
 (c) $V_s \sqrt{\frac{\phi}{2\pi}}$ (d) $\frac{V_s}{\pi}$

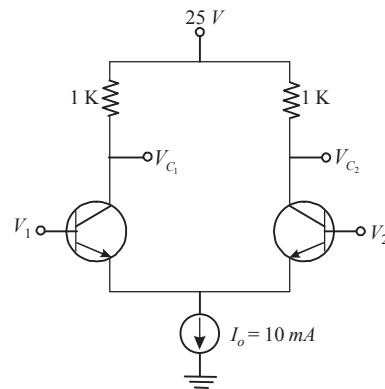
39. Consider the following parts of a dc machine:

1. Yoke
2. Armature core
3. Brushes
4. Pole core

Which of the above parts are subjected to iron loss?

- (a) 1 and 2 only (b) 2 only
 (c) 1 only (d) 1, 2, 3 and 4

40. In the difference amplifier as shown below the different output for is $V_1 = +5$ V, $V_2 = 0$



- (a) 0 V (b) 5 V
 (c) 10 V (d) 15 V

41. In scott connection, if the turns ratio of main transformer is K, then the teaser transformer has turns ratio of

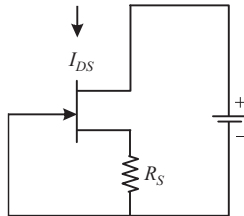
- (a) $\frac{2K}{\sqrt{3}}$ (b) $\frac{\sqrt{3}K}{2}$
 (c) $\frac{\sqrt{3}}{K}$ (d) $\frac{K}{2}$

42. A 3-phase thyristor controlled rectifier is feeding a purely resistive load on the DC side. The firing angle of the 6 thyristors of the converter is 90° . AC side is connected to a balanced 3-phase supply. Considering only the fundamental of the input

current, active power P and reactive power Q estimated at the AC side of the rectifier are

- (a) $P = 0, Q \neq 0$ (b) $P \neq 0, Q \neq 0$
 (c) $P = 0, Q = 0$ (d) $P \neq 0, Q = 0$

43. The JFET in the above circuit has an $I_{DSS} = 10 \text{ mA}$, $V_p = 5 \text{ V}$. The value of the resistance R_s for a drain current of $I_{DS} = 6.4 \text{ mA}$ is



- (a) $1.06 \text{ k}\Omega$ (b) 560Ω
 (c) 470Ω (d) 156Ω

44. In mode '0' (zero) operation of 8255, the ports can be used as port:

- (a) A as input port only (b) B as output port only
 (c) A as output port only (d) A as input or output port

45. Which one of the following modulation techniques has got maximum SNR?

- (a) AM-SSB (b) AM-DSB
 (c) FM (d) AM-SC

46. Load frequency controllers are carried out with

- (a) P controllers only (b) I controllers only
 (c) D controllers only (d) PID controllers

47. Three identical generators supply power in a system having lossless transmission lines. Generator 1 is equipped with a speed governor that maintains its speed constant at the rated value while generators 2 and 3 have governors with droops of 5% and 4% respectively. For a given increase in system load in the steady state

- (a) Generators 1, 2, 3 will share the increased load in the ratio of 0: 5: 4
 (b) Generators 1, 2, 3 will share the increase load equally
 (c) Generators 1, 2, 3 will share the increased load in the ratio of 0: 4: 5
 (d) Generators 1 will alone take the entire increased load and the output of generators 2 and 3 will remain unchanged

48. A Δ/Δ connected transformer is connected to V/V connected transformer. The ratio of VA rating of V/V connected transformer is

- (a) 57.7 % (b) 100 %
 (c) 50 % (d) 75%

49. A dc motor from a type A chopper is switched to type B chopper. How does the motor operate when type A and B are in operation respectively?

- (a) Plugging and motoring
 (b) Motoring and plugging
 (c) Regenerative braking and motoring
 (d) Motoring and regenerative braking

50. The efficiency of a class B amplifier is 72% when the supply voltage is 24 V. The peak to peak output voltage is

- (a) 20 V (b) 22 V
 (c) 25 V (d) 16 V

51. If the probability of a message 1/4, then the information in bits is

- (a) 1 bit (b) 2 bit
 (c) 4 bit (d) 8 bit

52. A 16 bit memory address register can address memory location of

- (a) 16 k (b) 32 k
 (c) 64 k (d) 128 k

53. Load flow studies must be made on a power system before

- (a) Making short circuit studies but not for transient stability studies on the power system
 (b) Making transient stability studies but not for short circuit studies circuit studies on the power system
 (c) Making both short circuit and transient stability studies on the power system
 (d) For neither making short circuit studies not transient stability studies on the power system

54. A conventional telephone line with 3 kHz bandwidth and having 30 dB signal-to-noise ratios can carry information at a rate of

- (a) 30 kbps (b) 15 kbps
 (c) 3 kbps (d) 16 Mbps

55. A dc transistor chopper supplied from a fixed voltage dc source feeds a fixed resistive inductive load and a free wheeling diode. The chopper operates at 1 kHz and 50% duty cycle. Without changing the value of the average dc current thought the load, if it is desired to reduce the ripple content of the load current, the control action need will be to

- (a) Increase the chopper frequency keeping its duty cycle constant
 (b) Increase the chopper frequency and duty cycle in equal ratio
 (c) Decrease only the chopper frequency
 (d) Decrease only the duty cycle

56. Neglecting losses, if the power transformed inductively is equal to power transformed conductively in an autotransformer, then the secondary to primary ratio of transformer is

- (a) 0.5 (b) 2
 (c) 1.5 (d) 1.25

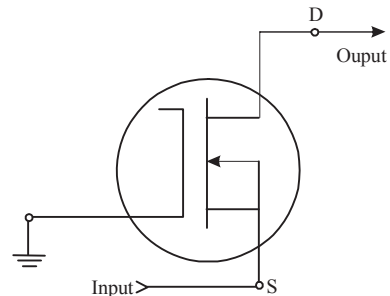
57. In modelling the equivalent circuit of a short length overhead transmission line, the line resistance and inductance are only considered because line capacitance to ground is

- (a) Equal to zero (b) Finite but very small
 (c) Finite but very small (d) Infinite

58. A separately excited dc motor is started using a 3 phase ac/dc controlled rectifier using 'soft starting'. For limiting the starting current, it is required that firing angle should be

- (a) Gradually increased from 0° to 180°
 (b) Fixed at 30°
 (c) Gradually reduced from 180° to 30°
 (d) Gradually increased from 30° to 180°

59. The field, which is never present in an assembly language statement, is
 (a) Opcode (b) Operand
 (c) Continue (d) Comment
60. A JFET is set up as a follower, with $\mu = 200$, $r_d = 100k$ and source load resistor $R_L = 1k$ the output resistance R_o is
 (a) 1000Ω (b) 500Ω
 (c) 333Ω (d) 666Ω
61. An example of 8085-instruction that uses direct addressing is
 (a) RLC (b) STA
 (c) RRC (d) CMA
62. Consider the following statements about FM:
 1. Modulation index determines the number of significant sideband components.
 2. Theoretical bandwidth is infinite.
 3. Carrier suppression is not possible.
 4. Sidebands are not symmetric about carrier
 Which of the above statements is/are correct?
 (a) 1, 2, 3 and 4 (b) 1 and 2 only
 (c) 3 and 4 only (d) 3 only
63. The Fermi function for an electron is $f(E)$, where E is energy. Then, the Fermi function for a hole is
 (a) $f(E)$ (b) $1 - f(E)$
 (c) $1/f(E)$ (d) $1 + f(E)$
64. In an LC series circuit connected to a dc supply of E volts via a thyristor when it turns off, the voltage that appears across the thyristor is
 (a) $+E$ (b) $+2E$
 (c) $-E$ (d) $-2E$
65. In an autotransformers, power is transferred through
 (a) Conduction process only
 (b) Induction process only
 (c) Both conduction and induction processes
 (d) Mutual coupling
66. For a 3-element feed water control in a coal fired thermal power station, Measurements of level of water in the boiler drums is made so that the water level does not
 (a) Exceed a specified upper limit
 (b) Fall below a specified lower limit
 (c) Violate specified upper and lower limits
 (d) Restrict to a specified limit
67. In 8085 microprocessor, the order of priority for hardware interrupts, are
 (a) INTR, RST 7-5, RST 6-5, TRAP
 (b) TRAP, RST 7-5, RST 6-5, RST 5-5, INTR
 (c) TRAP, INTR, RST 5-5, RST 6-5, RST 7-5
 (d) INTR, RST 5-5, RST 6-5, RST 7-5, TRAP
68. The de-emphasis filter in an FM receiver comes
 (a) Before FM demodulator
 (b) After FM demodulator and before baseband filter
 (c) After baseband filter
 (d) Before RF amplifier
69. If a fixed amount of power is to be transmitted over certain length with fixed power loss, it can be said that volume of conductor is
 (a) Inversely proportional to square of the voltage and that of power factor of the load
 (b) Inversely proportional to square of the voltage and square of power factor of the load
 (c) Proportional to square of voltage and that of power factor of the load
 (d) Proportional to magnitude of the voltage only
70. Consider the following statements:
 Pumped storage plants when operated in interconnected power systems serve to
 1. Increase load factor of steam plant.
 2. Provide added capacity to meet peak loads
 3. Decrease load factor of steam plant.
 4. Provide added capacity to meet base loads
 Which of the above statements are correct?
 (a) 1, 2, 3 and 4 (b) 1 and 3 only
 (c) 1 and 2 only (d) 3 and 4 only
71. Consider the following devices:
 1. SCR 2. GTO
 3. BJT 4. MOSFET
 5. IGBT
 Which of these devices do not belong to the family of transistors?
 (a) 1 and 2 only (b) 1, 2 and 3 only
 (c) 2, 3 and 5 only (d) 1, 2, 3, 4 and 5
72. It is advisable to use autotransformer if the transformation ratio is
 (a) Greater than 1 (b) Near to 1
 (c) 0.25 (d) 0.5
73. Thermal runaway is not encountered in FETs because
 (a) I_{DS} has a zero temperature coefficient
 (b) I_{DS} has a negative temperature coefficient
 (c) I_{DS} has a positive temperature
 (d) The mobility of the carries increases with increase in temperature
74. The opcode for the instruction "Add Immediately to Accumulator with carry" in 8085 microprocessor is
 (a) ADI (b) ACI
 (c) ADC (d) ADD
75. The FET shown below is a



- (a) Common drain (b) Common gate
(c) Common source (d) Common source

76. Consider the following statements:

1. Nuclear fission occurs whenever Uranium reacts with a neutron.
2. Nuclear fission is accompanied by the release of neutrons and gamma rays.
3. About 200 MeV of energy is released in the fission of a U^{235} nucleus is released mainly as kinetic energy of gamma radiations.
4. Energy from the fission of U^{235} nucleus is released mainly as kinetic energy of the neutrons and the energy of gamma radiations.

Which of the above statements are correct?

- (a) 1, 2, 3 and 4
(b) 3 and 4 only
(c) 2, 3 and 4 only
(d) 1, 2 and 4 only

77. The most noise immune system is

- (a) SSB (b) PCM
(c) PDM (d) PWM

78. A 10 km long lossless transmission lines has a reactance of $0.3 \Omega/\text{km}$ and negligible shunt capacitance. The value of

$$\frac{-A}{\equiv C} \frac{B}{D} \downarrow \text{ is}$$

- (a) $\frac{-1}{\equiv j3} \frac{0}{1} \downarrow$ (b) $\frac{-1}{\equiv 0.3} \frac{0}{1} \downarrow$
(c) $\frac{-1}{\equiv 0} \frac{j3}{1} \downarrow$ (d) $\frac{-j3}{\equiv 1} \frac{0}{1} \downarrow$

79. The content of the programme counter of an 8085 microprocessor is

- (a) The total number of instructions in the program already executed
(b) The total number of time a subroutine is called
(c) The memory address of the instruction that is being currently executed
(d) The memory address of the instruction that is to be executed next

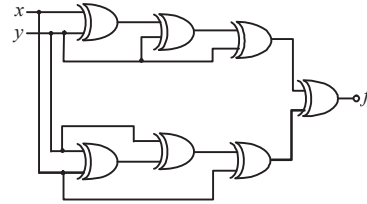
80. A 3000 Hz bandwidth channel has a capacity of 30 kbps. The signal-to noise ratio of the channel is

- (a) 20 dB (b) 25 dB
(c) 30 dB (d) 40 dB

81. In a 3-phase induction machine, motoring, generating and braking operations take place in the range of slip "S" is:

- (a) $1 > S > 0$, $0 > S > -2$ and $S > 1$
(b) $S > 1$, $1 > S > -1$ and $0 > S > 1$
(c) $S > 1$, $0 > S > -1$ and $1 > S > 0$
(d) $0 > S > -1$, $S > 1$ and $1 > S > 0$

82. The circuit shown below generates the functions of



- (a) $x \oplus y$ (b) 0
(c) $X\bar{Y} + YX + \bar{Y}X$ (d) $X \cdot \bar{Y}$

83. Match list I with list II and select the correct answer using the code given below the lists:

List I

List II

- (a) 1. AB
(b) 2. $\overline{AB}$
(c) 3. A + B
(d) 4. $\overline{A+B}$

Codes:

	A	B	C	D
(a)	3	1	4	2
(b)	2	1	4	3
(c)	3	4	1	2
(d)	2	4	1	3

84. Match list I with list II and select the correct answer using the code given below the lists:

List I

List II

- (a) All types of faults (a) Negative sequence current are present
(b) All unsymmetrical faults (b) Zero sequence current are present
(c) Faults involving ground with natural of the system grounded (c) Zero sequence currents are absent
(d) Fault involving Ground with floating neutral (d) Positive sequence current are present

85. The power factor of an induction motor operating at no load will have a value around

- (a) 0.9 lag (b) 0.2 lead
(c) 0.2 lag (d) 0.9 lead

86. LXI SP 7FFFH
MVI A, 25H
XRI 02H
PUSH PSW
POP H
MOV A L
ORI 10H
HLT

What are the contents of A, H, L, SP and PSW registers after executing the above set of instructions? Assume undefined flags always remain cleared.

- (a) 10H, 25H, 00H, 7FFFH, 00H respectively
- (b) 14H, 27H, 04H, 7FFFH, 04H respectively
- (c) 14H, 25H, 00H, 7FFFH, 04H respectively
- (d) 10H, 27H, 04H, 7FFFH, 00H respectively

87. The MMF produced by the rotor currents of a 3-phase induction motor

- (a) Rotates at the speed of rotor in the air gap
- (b) Is at stand with respect to stator MMF
- (c) Rotates at slip speed with respect to stator MMF
- (d) Rotates at synchronous speed with respect to rotor

88. The restriking voltage is measured in

- (a) RMS value
- (b) Peak value
- (c) Instantaneous value
- (d) Average value

89. In a PWM inverter, f_o and f are the frequencies in Hz for the carrier signal and reference signal respectively. Then the number of pulses per half cycle is

- (a) $N = \frac{f}{f_o}$
- (b) $N = \frac{f}{2f_o}$
- (c) $N = \frac{f_o}{2f}$
- (d) $N = \frac{f_o}{f}$

90. A squirrel cage induction motor having a rated slip of 2% on full load had a starting torque of 50% of full load torque. The starting current is

- (a) Two times the full load current
- (b) Four times the full load current
- (c) Five times the full load current
- (d) Equal to the full load current

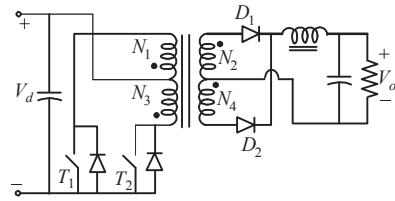
91. If a line of surge impedance Z_o is terminated in an impedance Z then the reflection for current and voltage surge at termination are given respectively by

- (a) $\frac{Z_o - Z}{Z_o + Z}, \frac{2Z}{Z_o + Z}$
- (b) $\frac{Z_o - Z}{Z_o + Z}, \frac{Z - Z_o}{Z_o + Z}$
- (c) $\frac{2Z_o}{Z_o + Z}, \frac{2Z}{Z_o + Z}$
- (d) $\frac{2Z_o}{Z_o + Z}, \frac{Z - Z_o}{Z_o + Z}$

92. Under voltage relays are mainly used for

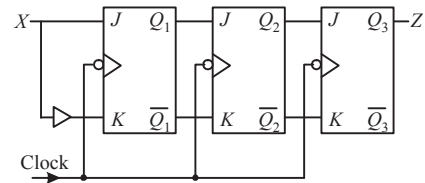
- (a) Motor protection
- (b) Transformer protection
- (c) Transformer line protection
- (d) All of the above

93. In push-pull type DC-DC converter the output voltage



- (a) $V_o = 2 \frac{N_2}{N_1} \cdot V_d \frac{t_{ON}}{t_{ON} + t_{OFF}}$
- (b) $V_o = \frac{N_2}{N_1} \cdot V_d \frac{t_{ON}}{t_{ON} + t_{OFF}}$
- (c) $V_o = 2 \frac{N_2}{N_1} \cdot V_d \frac{t_{ON}}{t_{OFF}}$
- (d) $V_o = \frac{N_2}{N_1} \cdot V_d \frac{t_{ON}}{t_{OFF}}$

94. Circuit shown below is a



- (a) Shift register
- (b) Binary counter
- (c) Ripple counter
- (d) Sequence detector

95. Fibre optic cables are used in power system applications mainly for

- (a) SCADA
- (b) Communication between power station and sub station
- (c) Communication between power station and load control center
- (d) All of the above

96. Consider the following statements:

The suitable configuration of HVDC converter is decided on the requirements of

1. High pulse number.
2. Converter transformer utilization factor should be near to unity.

Which of the above statements is/are correct?

- (a) 1 only
- (b) Both 1 and 2
- (c) Neither 1 nor 2
- (d) 2 only

97. A shift register with the serial output connected back to the serial input is a

- (a) Feedback shift register
- (b) Shift register counter
- (c) Universal shift register
- (d) Serial to parallel converter

98. The average output voltage of a fly-back converter is $V_o = 24$ at a resistive load of $R = 0.8 \Omega$. The duty cycle ratio is $a = 50\%$ and the switching frequency is $f = 1 \text{ kHz}$. The on-state voltage drop of transistors and diodes are $V_{T_s} = 1.2 \text{ V}$ and $V_d = 0.7 \text{ V}$ respectively. The turn ratio of the transformer is $N_s/N_p = 0.25$. What is the efficiency of the converter?
- (a) 86.5% (b) 96%
(c) 75% (d) 90%
99. Which of the following counter results in least delay?
- (a) Ring counter (b) Ripple counter
(c) Synchronous counter (d) Asynchronous counter
100. In how many different modes a universal shift register operates?
- (a) 2 (b) 3
(c) 4 (d) 5

ANSWER KEYS

1. (a)	2. (a)	3. (b)	4. (b)	5. (a)	6. (c)	7. (d)	8. (d)	9. (a)	10. (a)
11. (a)	12. (b)	13. (c)	14. (a)	15. (a)	16. (c)	17. (b)	18. (c)	19. (d)	20. (d)
21. (c)	22. (b)	23. (d)	24. (b)	25. (d)	26. (b)	27. (c)	28. (d)	29. (c)	30. (b)
31. (c)	32. (d)	33. (d)	34. (a)	35. (c)	36. (b)	37. (b)	38. (b)	39. (b)	40. (c)
41. (b)	42. (c)	43. (d)	44. (d)	45. (c)	46. (d)	47. (d)	48. (d)	49. (d)	50. (b)
51. (b)	52. (c)	53. (c)	54. (a)	55. (a)	56. (a)	57. (b)	58. (c)	59. (c)	60. (c)
61. (b)	62. (b)	63. (b)	64. (c)	65. (c)	66. (c)	67. (b)	68. (b)	69. (c)	70. (c)
71. (a)	72. (b)	73. (b)	74. (b)	75. (b)	76. (a)	77. (b)	78. (c)	79. (d)	80. (c)
81. (a)	82. (a)	83. (d)	84. (a)	85. (c)	86. (b)	87. (b)	88. (b)	89. (c)	90. (c)
91. (b)	92. (d)	93. (c)	94. (a)	95. (d)	96. (d)	97. (b)	98. (b)	99. (c)	100. (c)

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