DETAILED SOLUTIONS

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# ESE 2025 : Prelims Exam
## CLASSROOM TEST SERIES

## E & T ENGINEERING

## Test 12

**Section A :** Advanced Communication + Electronic Measurements and Instrumentation

**Section B :** Signals and Systems-1 + Basic Electrical Engineering-1

**Section C :** Analog & Digital Communication Systems-2

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

## Detailed Explanation

## Section A : Advanced Communication + Electronic Measurements and Instrumentation

**1. (b)**

$$\text{Normalized frequency, } V = \frac{2\pi a}{\lambda}(\text{NA})$$

$$\therefore \quad V = \frac{2\pi\times\left(\frac{30}{2}\times 10^{-6}\right)\times 0.16}{0.9\times 10^{-6}} = 16.8$$

Number of guided modes in the fibre is given by

$$N = \frac{V^2}{2}$$

$$= \frac{(16.8)^2}{2} = 141$$

**2. (d)**

We have,

$$\sin \phi_{max} = \text{NA}$$

$$\text{NA} = \sin 30° = 0.5$$

$$\Delta = 0.03$$

The relative index difference,

$$\Delta = 1 - \frac{n_2}{n_1}$$

$$\therefore \quad \frac{n_2}{n_1} = 1 - \Delta = 1 - 0.03 = 0.97$$

The critical angle at the core-cladding interface is given by

$$\sin \phi_c = \frac{n_2}{n_1} = 0.97$$

$$\phi_c = \sin^{-1}(0.97)$$

$$= 75.93°$$

$$\phi_c \approx 76°$$

**3. (c)**

Material dispersion refers to the wavelength dependency of the refractive index of a material, causing different spectral components of a signal to propagate at varying speeds, leading to temporal broadening of the signal pulse.

- Waveguide dispersion is significant in single-mode fibers not in multimode fibers as different propagation modes in a fiber travel at different speeds.
- Intermodal dispersion occurs in multimode fibers.
- When wavelength 870 nm and 1300 nm is used, dispersion is minimized which is known as zero dispersion wavelength.

Hence, statements 1 and 4 are correct.

**4.** **(c)**

- Impurities like hydroxyl (OH–) ions and transition metals absorb light, contributing to absorption losses.
- The scattering coefficient in Rayleigh scattering is inversely proportional to the fourth power of the wavelength. Hence, scattering losses dominate at shorter wavelengths.
- Bending losses are significant in both single-mode and multimode fibers.
- A theoretical attenuation minimum for silica fibres occurs at a wavelength of 1550 nm.

**5.** **(b)**

The dispersion per unit length of the fiber is given as,

$$\frac{\Delta T_{mat}}{L} = \Delta\tau_s \cdot D_{\text{mat}}$$

Here, $D_{\text{mat}}$ is the material dispersion coefficient and $\Delta\tau_s$ is the spectral width of the source. Thus,

$$\Delta T_{\text{mat}} \text{ (per km)} = 0.15 \times 1.5 = 0.225 \text{ ns/km}$$

The material dispersion for a 15 km length of a fiber is given as

$$\Delta T_{\text{mat}} = \Delta T_{\text{mat}} \text{ (per km)} \times L$$
$$= 0.225 \times 15 \text{ ns} = 3.375 \text{ ns}$$

**6.** **(d)**

- Throughput:

$$= \frac{\text{Window size}}{\text{RTT}} = \frac{64\times 8\times 2^{10}}{50\times 10^{-3}} = 10.48 \text{ Mbps}$$

  Hence, the throughput is limited to 10.48 Mbps by window size.
- The link speed is the upper limit : 10 Mbps. Thus, the maximum throughput is 10 Mbps.
- Doubling the window size doubles the throughput.
- Higher RTT reduces throughput, since

$$\text{Throughput} \propto \frac{1}{\text{RTT}}$$

**7.** **(a)**

- VLANs reduce broadcast domains by segmenting networks.
- VLANs operate at layer 2 (data link layer)
- VLAN tagging is standardized by IEEE 802.1Q.
- VLANs can span multiple switches using trunk ports.

**8.** **(a)**

- Packet switching is efficient for bursty traffic as it dynamically allocates resources.
- Circuit switching is the foundation of traditional telephony systems which establishes a dedicated circuit for the entire call/session.
- Packet switching introduces higher delays due to queuing and routing.
- Circuit switching reserves resources for the entire call/session.

**9. (b)**

- Uplink frequencies are higher than downlink frequencies to avoid interference. Further, Higher frequencies tend to experience greater atmospheric attenuation. Since, ground stations typically have more power available to compensate for the losses, uplink frequencies are kept higher.
- Lower downlink frequencies result in reduced free space path loss.
- Both uplink and downlink frequencies are affected by rain attenuation especially in Ku and Ka bands.

**10. (c)**

$$\text{S/N} = \text{C/N} + (\text{FM improvement factor}) - \text{Noise Margin}$$

$$D = \text{FM Improve factor} = 10\log\left(\frac{3}{2}\beta^2\right)$$

$$= 10\log\left[\frac{3}{2}\left(\frac{\Delta f}{f_m}\right)^2\right]$$

$$= 10\log\left[\frac{3}{2}\left(\frac{10}{5}\right)^2\right]$$

$$= 10\ \log[6] = 7.78$$

$$\text{C/N} = \text{S/N} - \text{D} + \text{Noise Margin}$$

$$= 62 - 7.78 + 11.8$$

$$= 66.02 \cong 66\ \text{dB}$$

**11. (a)**

Speed of the mobile phone, $v$ = 80 km/h

Cell radius, $R$ = 1 km

$d_{\text{threshold}}$ = 0.8 km

The total time taken to traverse the entire cell radius R is given by:

$$t_{\text{cell}} = \frac{R}{v} = \frac{1}{80} \times 3600 = 45 s$$

The distance between the handoff initiation point and the cell boundary is the handoff margin $d_{\text{margin}}$. The time for the mobile to traverse this distance is:

$$t_{\text{handoff}} = \frac{d_{\text{margin}}}{v} = \frac{0.8\ \text{km}}{80} \times 3600$$

$$= 36\ \text{sec}$$

- A larger cell means a user spends more time within the cell's coverage area before needing to switch to another cell. Therefore, the frequency of handoffs decreases.
- A faster-moving user crosses cell boundaries more frequently resulting in increasing in the number of hand-offs.
- The handoff margin is the difference between the signal strength at which a handoff is initiated and the minimum acceptable signal strength. A smaller margin means that small fluctuations in signal strength can cause the signal to drop below the minimum before the handoff is completed, resulting in a dropped call.

- Signal strength varies due to distance from the base stations, and it fluctuates as the mobile transitions between cells.

Hence, statements 1, 2 and 3 are correct.

**12. (d)**

Initial area covered by the system = 100 km$^2$

Initial number of cells = 10

Frequency reuse factor, $N = 4$

When each cell is split into 4 smaller cells,

$$\text{Total cells after splitting} = \text{Initial number of cells} \times 4 = 10 \times 4 = 40$$

- The frequency reuse factor (N) remains constant because the splitting of cells does not change the frequency allocation scheme.
- The system capacity increases because splitting cells allows for more users to be accommodated within the same area. Smaller cells mean more base stations, which increases the number of channels available in the system.
- Interference per cell does not decrease because the same frequencies are reused in adjacent cells according to the reuse factor. Splitting cells often increases interference due to reduced cell size and closer proximity of base stations.

**13. (c)**

The RSA encryption formula is:

$$C = p^e \bmod n$$

$$C = 4^7 \bmod 33 = 16384 \bmod 33$$

$$16384 \div 33 = 496 \text{ remainder } 16$$

Thus, the cipher text is $C = 16$

- Larger $e$ values enhance security but require more computation.
- A larger $n$ increases the difficulty of factoring $n$ into its prime factors, improving security.
- In RSA, the private key (d) is used to decrypt the ciphertext as $p = C^d \bmod n$.

**14. (d)**

Total bandwidth: 25 MHz = $25 \times 10^6$ Hz

Channel bandwidth = 200 kHz = $200 \times 10^3$ Hz

Each channel supports 8 time slots.

The total number of channels can be calculated as

$$\text{Total channels} = \frac{\text{Total bandwidth}}{\text{Channel bandwidth}}$$

$$= \frac{25\times10^6}{200\times10^3} = 125$$

- Each channel supports 8 time slots, and each time slot is used for one call. Therefore, the total number of simultaneous calls supported is:

$$\text{Total calls} = \text{Total channels} \times \text{Time slots per channel} = 125 \times 8 = 1000 \text{ calls}$$

- Each channel has 8 time slots, with each slot supporting one call.
- Larger bandwidth allows for more channels, increasing capacity.
- If the time slots per channel increase from 8 to 16, the capacity will double.
- GSM systems are efficient for handling large-scale voice communication, as they use time division multiplexing to maximize capacity.

**15. (b)**

$$f_{\text{muf}} = f_c\sqrt{1+\left(\frac{D}{2h}\right)^2}$$

$$= 5\sqrt{1+\left(\frac{400}{2\times300}\right)^2} = 5\sqrt{1+0.444} = 5\times1.2$$

$$f_{\text{muf}} = 6 \text{ MHz}$$

**16. (c)**

Operating frequency ($f$) = 12 GHz
Link distance ($d$) = 10 km
Fade margin ($F_m$) = 20 dB

The general formula for the received power ($P_r$) is:

$$P_r = P_t + G_t + G_r - L_p - F_m$$

$P_t$ = transmitted power
$G_t, G_r$ = Antenna gains
$L_p$ = Path Loss
$F_m$ = Fade margin

$$L_p(\text{dB}) = 20 \log (d) + 20 \log(f) + 20 \log(4\pi/c)$$

$$L_p = 20\log(10000)+20\log_{10}(12\times10^9)+20\log\left(\frac{4\pi}{3\times10^8}\right)$$

$$= 80 + 201.6 - 147.5 = 134.1 \text{ dB}$$

The required link budget is:

$$P_t + G_t + G_r - L_p \geq F_m$$

$$P_t + G_t + G_r \geq 154.1 \text{ dB}$$

- Higher frequencies increase path loss, making the link more susceptible to fading. This is because
  - → path loss increase with 20 log ($f$) making the received power smaller.
  - → Higher frequencies are more prone to multipath effects, leading to severe fading in cases of destructive interference.
- Multipath fading depends on frequency; higher frequencies suffer more due to smaller wavelength.
- A larger fade margin allows the system to tolerate more fading before the signal drops below the receiver's sensitivity threshold.
- The shorter distances can reduce the fading effects.

**17.** **(c)**

CDMA is most efficient during handoffs as it allows soft handoffs by maintaining multiple connections simultaneously, unlike FDMA and TDMA.

**18.** **(b)**

$$\text{Time slot duration} = \frac{\text{Frame duration}}{\text{Number of time slots}} = \frac{100\text{ ms}}{10} = 10\text{ ms}$$

**19.** **(b)**

We know, Number of revolutions = $KVI \cos\phi \times t$ ...(i)

$$\therefore \quad \text{Energy meter constant, } K = \frac{2208}{230\times4\times1\times6} = \frac{2208}{5520}$$

$$\Rightarrow \quad K = 0.4 \text{ rev/Whr}$$

$$\Rightarrow \quad K = 400 \text{ rev/kWhr}$$

Using equation (i),

$$1104 = (400 \times 230 \times 5 \times \cos\phi \times 4) \times 10^{-3}$$

$$\Rightarrow \quad \cos\phi = \frac{1104\times10^3}{400\times230\times5\times4} = \frac{1104\times10^3}{1840000} = 0.6$$

**20.** **(c)**

$S$ : Standard Resistance ⇒ $S = 0.8\ \text{M}\Omega$

$R$ : Unknown Resistance ⇒ $R = ?$

$G$ : Galvanometer resistance ⇒ $G = 20\ \text{k}\Omega$

$\theta_1$ : Deflection with standard resistor ⇒ $\theta_1 = 61$ div

$\theta_2$ : Deflection with unknown resistor ⇒ $\theta_2 = 82$ div

The current through the galvanometer is inversely proportional to the resistance of the circuit. Since, the deflection of galvanometer is proportional to the current in the circuit, we have

$$\frac{\theta_1}{\theta_2} = \frac{R+G}{S+G}$$

$$\frac{61}{82} = \frac{R+20000}{800000+20000}$$

$$\frac{820000\times61}{82} = R + 20000$$

$$610000 = R + 20000$$

$$\Rightarrow \quad R = 590 \times 10^3\ \Omega = 0.59\ \text{M}\Omega$$

**21.** **(c)**

For $R_1$ and $R_2$ in parallel, the equivalent resistance is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \qquad \text{...(i)}$$

$$\Rightarrow \quad R = \frac{R_1R_2}{R_1+R_2} = \frac{5\text{ k}\times10\text{ k}}{5\text{ k}+10\text{ k}} = \frac{50\text{ k}}{15} = \frac{10}{3}\text{k}\Omega$$

Using equation (i),

$$\frac{\Delta R}{R^2} = \frac{\Delta R_1}{R_1^2} + \frac{\Delta R_2}{R_2^2}$$

Given, $\Delta R_1 = 0.5\ \text{k}\Omega,\ \Delta R_2 = 0.5\ \text{k}\Omega$

$$\therefore \quad \frac{\Delta R}{R} = \left(R \times \frac{\Delta R_1}{R_1^2}\right) + \left(R \times \frac{\Delta R_2}{R_2^2}\right)$$

$$= \left(\frac{10}{3}\text{k} \times \frac{0.5\,\text{k}}{5\,\text{k} \times 5\,\text{k}}\right) + \left(\frac{10}{3}\text{k} \times \frac{0.5\,\text{k}}{10\,\text{k} \times 10\,\text{k}}\right)$$

$$= \left(\frac{1}{15}\right) + \left(\frac{1}{60}\right) = 0.0666 + 0.0166 \ = 0.0833$$

$$\Rightarrow \quad \frac{\Delta R}{R} \approx 8.33\%$$

**22. (c)**

$$\text{Average range of error} = \pm\frac{|\text{Maximum value} - \text{Minimum value}|}{2}$$

$$= \frac{\pm|20.27 - 20.08|}{2} = \frac{\pm 0.19}{2} = \pm 0.095$$

**23. (a)**

Given, $C = 0.8686\ \mu\text{F}$

$t = 0.5\ \text{min} = 0.5 \times 60\ \text{sec}$

We know, insulation resistance,

$$R = \frac{0.4343t}{C\log_{10}\left(\frac{V}{V_c}\right)} = \frac{0.4343 \times 0.5 \times 60}{0.8686 \times 10^{-6}\log_{10}\left(\frac{300}{30}\right)}$$

$$R = \frac{0.5 \times 0.5 \times 60 \times 10^6}{\log_{10}(10)} = 15 \times 10^6$$

$$\Rightarrow \quad R = 15\ \text{M}\Omega$$

**Note:**

We know, $V_c = Ve^{-t/RC}$

$$\Rightarrow \quad \ln\left(\frac{V}{V_c}\right) = \frac{t}{RC}$$

$$\Rightarrow \quad R = \frac{t}{C\ln\left(\frac{V}{V_c}\right)} = \frac{0.4343t}{C\log_{10}\left(\frac{V}{V_c}\right)}$$

**24.** **(b)**

Given, $R = 2025\ \Omega$

$= (2000 + 000 + 20 + 5)\ \Omega$

$\therefore$ Limiting error $= (2000 \times \pm 0.01\%) + (000 \times \pm 0.05\%) + (20 \times \pm 0.5\%) + (5 \times \pm 0.1\%)$

$= (0.2 + 0 + 0.1 + 0.005)$

$= 0.305\ \Omega$

**25.** **(b)**

Under balanced condition,

$$R_4 = \frac{R_2 R_3}{R_1} = \frac{20 \times 30}{10} = 60\ \Omega$$

The limiting error is given by,

$$\%\frac{\Delta R_4}{R_4} = \%\frac{\Delta R_2}{R_2} + \%\frac{\Delta R_3}{R_3} + \%\frac{\Delta R_1}{R_1}$$

$$= \pm 4\% \pm 6\% \pm 2\%$$

$$= \pm 12\%$$

Hence, the value of unknown resistance, $R_4 = 60\ \Omega \pm 12\%$

**26.** **(b)**

We have, 5th measurement, $X_5 = 15$ mA

$$\text{Average value, } \bar{X} = \frac{(10+12+14+16+15+13+15+10+11+14)\text{mA}}{10}$$

$$\bar{X} = 13 \text{ mA}$$

$\therefore$ Precision for 5th measurement is,

$$P_5 = 1 - \left|\frac{X_5 - \bar{X}}{\bar{X}}\right|$$

$$P_5 = 1 - \left|\frac{15-13}{13}\right| = 1 - \frac{2}{13} = \frac{11}{13}$$

**27.** **(d)**

Given, $I = 25\theta^n$

We know, for a moving iron instrument,

$$\theta = \frac{1}{2}\frac{I^2}{k_c}\frac{dL}{d\theta}$$

$$\Rightarrow \quad \frac{dL}{d\theta} = \frac{2k_c\theta}{I^2}$$

$$\Rightarrow \quad \frac{dL}{d\theta} = \frac{2 \times 0.5 \times \theta}{[25\theta^n]^2} = \frac{\theta}{625\theta^{2n}} = \frac{1}{625}\theta^{(1-2n)}$$

Integrating on both sides,

$$L = \frac{1}{625}\frac{\theta^{2-2n}}{(2-2n)} + \text{constant}$$

For $n$ = 0.5,

$$L = \left(\frac{\theta}{625}\right) + \text{constant}$$

**28. (b)**

$$\text{Span} = 1000 - 500 = 500°\text{C}$$

$$\therefore \quad \text{Dead zone} = \frac{0.25}{100} \times 500 = 1.25°\text{C}$$

Thus, a change of 1.25°C must occur before it is detected.

**29. (a)**

- The dynamometer voltmeter are most accurate form of voltmeter for measuring a.c voltage ranging from 50 to 500 V at power frequency.
- Electrostatic instruments has high resistance, drawing very less current and therefore, suitable for measuring high voltages.
- The thermocouple instrument is used primarily at radio frequencies. The r.f. current is passed through a heating element resulting in the rise in temperature of the thermocouple junction. The heating effect is relatively independent of frequency, making it suitable for RF measurements.
- Rectifier type instruments are well-suited for medium sensitivity voltage measurements in medium impedance circuits.

**30. (d)**

Voltage applied to deflecting plates is,

$$E_d = \frac{2dE_aD}{L\,l_d}$$

Substituting the given values: $E_a$ = 3000 V, $d$ = 5 mm = 5 × $10^{-3}$ m, $l_d$ = 3 cm = 3 x $10^{-2}$ m, $L$ = 30 cm = 0.3 m, $D$ = 3 cm = 3 × $10^{-2}$ m. We get,

$$E_d = \frac{2\times5\times10^{-3}\times3000\times3\times10^{-2}}{0.3\times3\times10^{-2}} = 100 \text{ V}$$

∴ Input voltage required for a deflection of 3 cm is,

$$= \frac{E_d}{\text{Gain}} = \frac{100}{200} = 0.5 \text{ V}$$

**31. (c)**

At balance,

$$(R_1 + j\omega L_1)\left(\frac{1}{j\omega C_4}\right) = R_3\left(R_2 + \frac{1}{j\omega C_2}\right)$$

$$-j\frac{R_1}{\omega C_4} + \frac{L_1}{C_4} = R_2R_3 - j\frac{R_3}{\omega C_2}$$

On equating real parts,

$$L_1 = R_2R_3C_4 = 500 \times 100 \times 0.1 \times 10^{-6} = 5 \text{ mH}$$

On equating imaginary parts,

$$R_1 = R_3\frac{C_4}{C_2} = 100\times\frac{0.1\times10^{-6}}{0.25\times10^{-6}} = 40\ \Omega$$

∴ The effective impedance is,

$$Z_1 = R_1 + j\omega L_1 = 40 + j2\pi \times 5000 \times 5 \times 10^{-3}$$
$$= (40 + j50\pi)\ \Omega$$

**32. (a)**

The Gauge factor is given by

$$G_f = 1+2v+\frac{(\Delta\rho/\rho)}{\varepsilon}$$

If piezoresistive effect is neglected, the gauge factor is,

$$G_f = 1 + 2v$$

$$\therefore \quad \text{Poisson's ratio, } v = \frac{G_f-1}{2} = \frac{4.5-1}{2} = \frac{3.5}{2} = 1.75$$

**33. (a)**

For a series RLC circuit, Quality factor

$$Q = \frac{\omega_0 L}{R_{eq}}$$

Let '$R$' be the resistance of coil,

$$\Rightarrow \quad (R + 0.5) = \frac{\omega_0 L}{Q} \quad \text{...(i)}$$

$$\text{Inductance, } L = \frac{1}{\omega_0^2 C} \qquad \left[\because \text{Resonant frequency, } \omega_0 = \frac{1}{\sqrt{LC}}\right] \quad \text{...(ii)}$$

$$\Rightarrow \quad L = \frac{1}{(2\times10^6)^2\times300\times10^{-12}} = \frac{1}{1200} \simeq 0.833\ \text{mH}$$

Using equation (i),

$$(R + 0.5) = \frac{2\times10^6\times0.833\times10^{-3}}{90} = 18.52\ \Omega$$

$$\therefore \quad \text{Effective resistance of coil, } R = 18.52 - 0.5$$
$$\approx 18\ \Omega$$

**34. (d)**

Multiplying power of shunt,

$$m = \frac{I}{I_m} = \frac{20}{2} = 10\ \backslash$$

If $R_{sh}$ is the resistance of the shunt, multiplying power,

$$m = 1+\frac{R}{R_{sh}}$$

$\therefore$ Resistance of shunt, $R_{sh} = \frac{R}{m-1} = \frac{0.05}{10-1}$

$\Rightarrow$ $R_{sh} = 5.56 \text{ m}\Omega$

In order that the meter read correctly at all frequencies, the time constants of meter and shunt circuits should be equal.

i.e., $\frac{L}{R} = \frac{L_{sh}}{R_{sh}}$

$\therefore$ Inductance of shunt, $L_{sh} = \frac{L}{R} R_{sh} = \frac{50\times10^{-6}}{0.05} \times 5.56 \times 10^{-3} = 5.56\ \mu\text{H}$

**35.** **(a)**

Data acquisition is the process of sampling signals that measure real-world physical conditions (analog) and convert the resulting samples into digital form for further processing. Thus, statements 1, 2 and 3 describe the essential functional operations of a digital data acquisition system

**36.** **(d)**

- Thermocouple : $E = a(\Delta\theta) + b(\Delta\theta)^2$ i.e. a non-linear relationship between voltage and tempearture.
- Thermistors: $R_{T1} = R_{T2} \exp\left[\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$ i.e. the resistance exponentially decreases with temperature.
- RTD: $R = R_0(1 + \alpha_1 T + \alpha_2 T^2 + \ldots + \alpha_n T^n + \ldots.)$ i.e. resistance non-linearly increases with temperature.
- IC sensors exhibit a linear relationship between output voltage/current and temperature.

**37.** **(a)**

Semiconductor strain gauges have the advantage that they have a high gauge factor of about ±130. This allows measurement of very small strains of the order of 0.01 microstrain.

**38.** **(a)**

LEO satellites have high speeds, leading to noticeable frequency shifts due to the Doppler effect, which must be corrected for proper communication.

## Section B : Signals and Systems-1 + Basic Electrical Engineering-1

**39.** **(c)**

We know, $\int_{t_1}^{t_2} x(t)\cdot\delta^m(t-t_0)dt = (-1)^m \left[\frac{d^m}{dt^m}(x(t))\right]_{t=t_0}$ ; $t_1 < t_0 < t_2$

where, '$m$' is the order of differentiation.

$$\Rightarrow \int_2^8 t^3 \cdot \ddot{\delta}(t-5)dt = (-1)^2 \frac{d^2}{dt^2}(t^3)\Big|_{t=5}$$

$$= \frac{d}{dt}(3t^2)\bigg|_{t=5}$$

$$= 6t\big|_{t=5}$$

$$= 6 \times 5 = 30$$

**40. (c)**

Given, $$x[n] = (j)^{\frac{n}{10}}$$

$$= \left(e^{j\frac{\pi}{2}}\right)^{\frac{n}{10}} = e^{j\frac{\pi n}{20}} = e^{j\omega_0 n}$$

$$\therefore \quad \frac{\omega_0}{2\pi} = \frac{(\pi/20)}{2\pi} = \frac{1}{40} = \frac{m}{N},$$

where $m$ is a positive integer such that $N$ is an integer

$$\Rightarrow \quad N = 40 \text{ samples}$$

**41. (d)**

We have, $$z(t) = x(t) + y(t)$$

Power of the signal $z(t) = P_z = \frac{1}{T}\int_0^T |z(t)|^2\, dt$

$$\Rightarrow \quad P_z = \frac{1}{T}\left[\int_0^T |x(t)+y(t)|^2\, dt\right]$$

$$= \frac{1}{T}\left[\int_0^T |x(t)|^2\, dt + \int_0^T |y(t)|^2\, dt + \int_0^T x(t)\cdot y^*(t)dt + \int_0^T x^*(t)y(t)dt\right]$$

Given, $x(t)$ and $y(t)$ are orthogonal i.e. $x(t) \cdot y^*(t) = x^*(t) \cdot y(t) = 0$

$$\Rightarrow \quad P_z = \frac{1}{T}\left[\int_0^T |x(t)|^2\, dt + \int_0^T |y(t)|^2\, dt + 0 + 0\right]$$

$$\Rightarrow \quad P_z = \frac{1}{T}\int_0^T |x(t)|^2\, dt + \frac{1}{T}\int_0^T |y(t)|^2\, dt$$

$$\Rightarrow \quad P_z = \sum_{n=-\infty}^{\infty} |X_n|^2 + \sum_{n=-\infty}^{\infty} |Y_n|^2 \qquad (\because \text{Parseval's Theorem})$$

$$= (1)^2 + (5)^2 + (10)^2 + (0.5)^2 + (2)^2 + (4)^2$$

$$= 1 + 25 + 100 + 0.25 + 4 + 16 = 146.25 \text{ W}$$

**42. (b)**

$$x(t) \longleftrightarrow X_n$$

$$x(t-1) \longleftrightarrow X_n e^{-jn\frac{2\pi}{T}(1)} \qquad \text{(using time shifting property)}$$

$$x\left(\frac{3}{2}t-1\right) \longleftrightarrow X_n e^{-jn\frac{2\pi}{T}(1)}$$

Time scaling operation will not change the Fourier series coefficients of the original signal. The Fourier series coefficients remain the same. However, there will be a change in the fundamental frequency.

**43. (b)**

We have, $$F^{-1}[(2+j\omega)\,X(\omega)] = Ce^{-t}u(t)$$

$$\Rightarrow \quad X(\omega) = \frac{C}{(1+j\omega)(2+j\omega)} = C\left[\frac{1}{1+j\omega}-\frac{1}{2+j\omega}\right]$$

Take inverse Fourier transform on both sides,

$$\Rightarrow \quad x(t) = Ce^{-t}u(t) - Ce^{-2t}u(t)$$

We know, $$\int_{-\infty}^{+\infty}|x(t)|^2\,dt = \frac{1}{2\pi}\int_{-\infty}^{+\infty}|X(\omega)|^2\,d\omega$$ (Parseval's relation)

$$\Rightarrow \quad \int_{-\infty}^{+\infty}|x(t)|^2\,dt = \frac{1}{2\pi}\times\pi = 0.5$$

$$\Rightarrow \quad \int_{-\infty}^{+\infty}\left|Ce^{-t}u(t)-Ce^{-2t}u(t)\right|^2 dt = 0.5$$

$$\Rightarrow \quad \int_{0}^{+\infty}\left[C^2e^{-2t}+C^2e^{-4t}-2C^2e^{-3t}\right]dt = 0.5$$

$$\Rightarrow \quad C^2\left[\frac{e^{-2t}}{-2}+\frac{e^{-4t}}{-4}-\frac{2e^{-3t}}{-3}\right]_0^{\infty} = 0.5$$

$$\Rightarrow \quad C^2\left[\frac{1}{2}+\frac{1}{4}-\frac{2}{3}\right] = 0.5$$

$$\frac{C^2}{12} = 0.5 \quad \Rightarrow \quad C^2 = 6 \quad \Rightarrow \quad C = \pm\sqrt{6}$$

Given, $x(t)$ is non-negative

$$\Rightarrow \quad C = \sqrt{6}$$

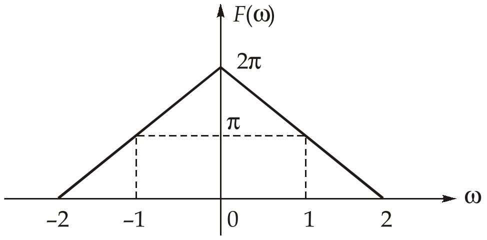
**44. (c)**

We know,

$$\begin{tikzcd}
A\,\mathrm{tri}\left(\frac{t}{T}\right) \arrow[r, leftrightarrow] \arrow[dr] & AT\,\mathrm{sinc}^2\left(\frac{\omega T}{2\pi}\right) \arrow[dl, "\text{Duality}"] \\
AT\,\mathrm{sinc}^2\left(\frac{tT}{2\pi}\right) \arrow[r, leftrightarrow] & 2\pi A\,\mathrm{tri}\left(\frac{-\omega}{T}\right) = 2\pi A\,\mathrm{tri}\left(\frac{\omega}{T}\right)
\end{tikzcd}$$

$$\therefore \qquad 2\,\text{sinc}^2\left(\frac{t}{\pi}\right) \longleftrightarrow 2\pi\,\text{tri}\left(\frac{\omega}{2}\right)$$

$$\Rightarrow \qquad F(\omega) = 2\pi\,\text{tri}\left(\frac{\omega}{2}\right)$$



$$\therefore \qquad F(\omega)\Big|_{\omega=1} = \pi$$

**45. (c)**

$$\left(\frac{1}{s^2+16}\right) \xleftrightarrow{L^{-1}} \frac{1}{4}\sin(4t)u(t)$$

$$\frac{d^2}{ds^2}\left(\frac{1}{s^2+16}\right) \xleftrightarrow{L^{-1}} (-1)^2 t^2 \left\{\frac{1}{4}\sin(4t)u(t)\right\}$$

{using multiplication by '$t$' property}

$$s\frac{d^2}{ds^2}\left(\frac{1}{s^2+16}\right) \xrightarrow{L^{-1}} \frac{d}{dt}\left[(-1)^2 t^2 \left\{\frac{1}{4}\sin(4t)u(t)\right\}\right] \qquad \{\text{Time differentiation}\}$$

$$= \frac{1}{4}\frac{d}{dt}\left[t^2\sin(4t)u(t)\right]$$

$$= \frac{1}{4}\left\{2t\sin(4t) + t^2 \times 4\cos(4t)\right\}u(t)$$

$$= \frac{t}{2}\sin(4t)u(t) + t^2\cos(4t)u(t)$$

$$\therefore \qquad s\frac{d^2}{ds^2}\left(\frac{1}{s^2+16}\right) + \left(\frac{1}{s^2+16}\right) \xleftrightarrow{L^{-1}} \frac{t}{2}\sin(4t)u(t) + t^2\cos(4t)u(t) + \frac{1}{4}\sin(4t)u(t)$$

$$\Rightarrow \qquad x(t) = \left[\left(\frac{2t+1}{4}\right)\sin(4t) + t^2\cos(4t)\right]u(t)$$

**At $t = \pi$:**

$$x(\pi) = \left(\frac{2\pi+1}{4}\right)\sin(4\pi) + \pi^2\cos(4\pi) = 0 + \pi^2 = \pi^2$$

**46. (d)**

Sampling frequency, $f_s = 1/T_s$ = 5000 Hz. The spectrum of the sampled signal is given as

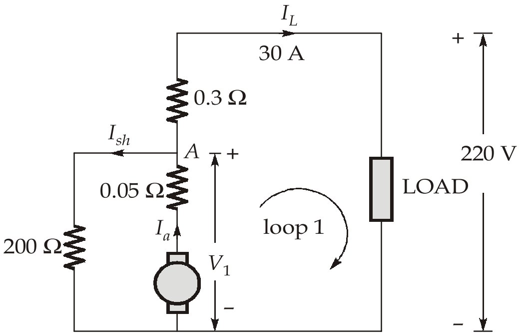
$$X_s(f) = f_s \sum_{m=-\infty}^{\infty} X(f - mf_s) = 5000 \sum_{m=-\infty}^{\infty} X(f - 5000m)$$

$$= 12500 \sum_{m=-\infty}^{\infty} [\delta(f - 5000m - 5000) + \delta(f - 5000m + 5000)]$$

So, $X_s(f)$ will contain frequency components $f$ = (5000 m ± 5000) where $m = 0$ to $\infty$ i.e., the input to LPF contains frequencies $f$ = 0, 5000, 10000, 15000, ....... After passing through LPF with cutoff frequency $f_c$ = 8 kHz, spectrum of $Y(f)$ will have frequency components $f_1$ = 0 Hz, $f_2$ = 5000 Hz only.

**47. (a)**

The circuit of given short shunt generator can be drawn as shown below:



On applying KVL in loop 1, we get

$$-V_1 + (0.3 \times 30) + 220 \text{ V} = 0$$

$$V_1 = 229 \text{ Volt}$$

Thus, shunt current, $I_{sh} = \dfrac{229}{200} = 1.145$ A

Now, on applying KCL at node A, we get

Armature current, $I_a = I_{sh} + I_L$

$$I_a = 1.145 + 30$$

$$I_a = 31.145 \text{ A}$$

Now again apply KVL in loop 1, we get

$$-E_g + I_a R_a + (0.3 \times 30) + 220 + 2 = 0 \qquad \text{(Volt drop by each brush = 1 volt)}$$

$$E_g = (31.145 \times 0.05) + 229 + 2$$

$$E_g = 229 + 1.56 + 2$$

$$E_g = 232.56 \text{ Volt}$$

**48. (c)**

We have,

Number of poles, $P = 8$

Number of conductors, $z = 500$

useful flux, $\phi = 0.05$ Wb/pole

**Case-I:** When it is lap connected; i.e., $A = P$

$$E = \frac{N\phi z}{60} \times \frac{P}{A}$$

$$E = \frac{1200 \times 0.05 \times 500}{60} = 500 \text{ Volt}$$

**Case-II:** When it is wave connected i.e. $A = 2$

$$E = \frac{N\phi z}{60} \times \frac{P}{A}$$

$$E = \frac{N \times 0.05 \times 500}{60} \times \frac{8}{2} = \frac{N \times 5}{3}$$

Now as per the question back emf is same for both the cases.

So,
$$\frac{5N}{3} = 500$$

$$N = 300 \text{ rpm}$$

**49.** **(b)**

Commutation ensures that the current supplied to the external load remains unidirectional, despite the rotating armature. This is done by using a commutator, which reverse the current direction in the armature windings as they cross the Magnetic Neutral Axis (MNA), maintaining a consistent output polarity.

**50.** **(d)**

We know that mutual inductance is given as

$$M = \frac{N_2\phi_1}{I_1} = \frac{600 \times 0.75 \times 10^{-3}}{7.5} = 0.06 \text{ H}$$

**51.** **(b)**

Under no load conditions, the power drawn by the prime mover of an alternator mainly goes into overcoming the internal losses of the alternator itself. These losses include mechanical losses (friction and windage losses), core losses and excitation losses.

Thus, option (b) is correct.

**52.** **(b)**

Zero power factor method is generally used to calculate the voltage regulation. This method is also known as the Potier Triangle Method.

**53.** **(d)**

Damper windings in a synchronous motor serve two primary purposes:

- Suppress rotor oscillation: They help to prevent hunting or dampen oscillations of the rotor when there are fluctuations in load, providing stability to the motor.
- Develop necessary starting torque: A synchronous motor cannot start by itself. During startup, the damper winding allows the motor to behave like an induction motor, producing starting torque until it reaches synchronous speed.

Thus, both (b) and (c) are correct functions of the damper windings.

**54.** **(c)**

Wind power is a renewable energy source. Wind turbines are designed to operate within a specific range of wind speeds. Wind turbines have a minimum "cut-in" wind speed below which they don't generate electricity and a maximum "cut-out" wind speed beyond which they are shut down to prevent damage. Wind energy is intermittent and dependent on wind speed, making it an unpredictable energy source. Hence, option (c) is correct.

**55.** **(a)**

When the field winding gets disconnected, the field current drops to zero, leading to a rapid decrease in flux $\phi$. Since speed is inversely proportional to flux, the motor tends to attain dangerously high speed (if not controlled by external means).

The given reason correctly states that speed of DC shunt motor is inversely proportional to the field flux $\phi$, which explains the assertion properly.

**56.** **(d)**

Solar photovoltaic systems typically have efficiencies ranging from 15% to 20% under ideal conditions. Solar thermal system, however, can achieve higher efficiencies, often in the range of 30% to 40% because they convert sunlight into heat, which is then used to generate electricity using steam and power turbines (a more efficient conversion method than direct PV conversion) Therefore, statement (I) is incorrect and statement (II) is correct.

**57.** **(a)**

For non-zero periodic impulse response,

$$\int_{-\infty}^{+\infty} |h(\tau)|\,d\tau = \infty \quad \rightarrow \quad \text{Unstable System}$$

$h(t) \neq 0$ for $t < 0 \rightarrow$ Non-causal system

$\therefore$ All periodic non-zero impulse responses are everlasting and thus, represents unstable and non-causal system.

## Section C : Analog & Digital Communication Systems-2

**58.** **(c)**

For a binary signalling scheme with white Gaussian Noise,

$$P_e = Q\left(\sqrt{\frac{E_d}{2N_0}}\right)$$

where $$E_d = \int_0^T [S_1(t) - S_2(t)]^2\,dt = \int_0^T A^2 \sin^2 \frac{\pi t}{T}\,dt = \frac{A^2 T}{2}$$

Thus, $$\frac{E_d}{2N_0} = \frac{A^2 T}{4N_0} = \frac{(4\times 10^{-4})^2 \times 3\times 10^{-6}}{4\times 2\times 10^{-15}} = 60$$

$\therefore$ $$P_e = Q\left(\sqrt{60}\right) = Q\left(2\sqrt{15}\right)$$

**59. (b)**

The minimum bandwidth required for transmitting the PCM wave is given by

$$\text{Bandwidth, B.W.} = \frac{R_b}{2}$$

where

$$R_b = nf_s$$

$$n = \log_2 64 = 6$$

$$R_b = 6 \times 8 \times 10^3 = 48 \text{ kbps}$$

$$\therefore \quad \text{B.W} = \frac{R_b}{2} = \frac{48\times 10^3}{2} = 24\text{ kHz}$$

**60. (d)**

We have, $\text{SNR} = 1.78 + 6n = 40$ dB

$\Rightarrow$ $n = 6.37 = 7$ bits/sample

Hence, the minimum number of bits per sample is 7 for a signal to quantization noise ratio of 40 dB.

Hence,

The number of samples in a duration of 10s

$= 8000$ (samples/sec) × 10 sec

$= 8 \times 10^4$ samples

The minimum storage capacity required

$= 7 \times 8 \times 10^4$

$= 5.6 \times 10^5$

$= 560$ k bits

**61. (a)**

Given, message signal $m(t) = A\sin(2\pi f_m t)$

To avoid slope overload,

$$\frac{\Delta}{T_s} \geq \left|\frac{d}{dt}m(t)\right|_{\max} \geq 2\pi f_m A$$

$$\Delta \geq \frac{2\pi f_m A}{f_s}$$

$$\Delta \geq \frac{2\pi\times 10^3 \times 1.5}{50\times 10^3}$$

$$\Delta_{\min} = 188.4 \text{ mV}$$

**62. (c)**

- In TDM, synchronization bits are include in each frame to help the receiver identify the beginning of a frame. These bits are a predefined pattern that the receiver can use to align its timing with the transmitted data ensuring proper demultiplexing of the channels. Without these synchronization bits, the receiver cannot distinguish between frames and may misinterpret the data.
- If the receiver loses synchronization (e.g. due to timing errors or missing synchronization bits), it cannot correctly align with the frames. This misalignment causes the receiver to assign

data from one channel to another, resulting in corrupted or unusable data for all channels. Synchronization is critical to maintaining the integrity of the transmitted information.

- Variable-length frames make synchronization more challenging, not simpler. In TDM, fixed length frames ensure predictable timing for each time slot making it easier for the receiver to maintain synchronization. Variable-length frames would require additional mechanisms to identify frame boundaries dynamically, adding complexity to the system.
- Timing recovery ensures that the receiver's clock matches the transmitter's clock. Accurate timing is necessary to correctly identify each time slot within the TDM frame. Without timing recovery, the receiver may fail to sample data at the correct intervals, leading to errors in demultiplexing and data loss.

**63. (d)**

$$\text{Efficiency} = \frac{\text{Data bits per frame}}{\text{Total bits per frame}} = \frac{8\times 12}{8\times 12+4} = 0.96$$

$$\%\ \text{efficiency} = 0.96 \times 100 = 96\%$$

**64. (c)**

$$\text{Bandwidth} = \frac{\text{Data Rate}}{\log_2 M}$$

$$= \frac{20\times 10^6}{\log_2 16} = \frac{20\times 10^6}{4} = 5\ \text{MHz}$$

**65. (b)**

- DPSK inherently avoids phase ambiguity, which is a common issue in coherent schemes like QPSK where the receiver must recover a reference carrier phase to correctly decode the data.
- DPSK has poorer BER performance than QPSK for the same $\frac{E_b}{N_0}$ because it relies on relative phase differences for decoding. Noise affecting both consecutive symbols in DPSK, result in error propagation.
- DPSK uses differential decoding, meaning the receiver only needs to detect the phase difference between consecutive symbols. This avoids the need for a coherent reference carrier (unlike QPSK).
- DPSK's detection depends on relative phase differences, making it less sensitive to frequency offsets or phase drift compared to coherent schemes like QPSK.

**66. (d)**

Channel bandwidth $B$ = 3.4 kHz

Received signal-to-noise ratio, SNR = 30 dB = $10^3$

Hence, the channel capacity using Shannon Hartley Theorem is

$$C = B \log_2(1 + \text{SNR})$$

$$= 3.4 \times 10^3 \log_2(1 + 10^3)$$

$$= 3.4 \times 10^3 \times 9.96$$

$$\cong 33.9 \times 10^3 \cong 34 \times 10^3\ \text{bits/second}$$

**67. (b)**

Entropy of the source is,

$$\begin{aligned}H(s) &= P_0\log_2\left(\frac{1}{P_0}\right)+P_1\log_2\left(\frac{1}{P_1}\right)+P_2\log_2\left(\frac{1}{P_2}\right)+P_3\log_2\left(\frac{1}{P_3}\right)\\ &= \frac{1}{3}\log_2(3)+\frac{1}{6}\log_2(6)+\frac{1}{4}\log_2(4)+\frac{1}{4}\log_2(4)\\ &= \frac{1}{3}\times 1.58+\frac{1}{6}\times(1+1.58)+\frac{1}{4}\times 2+\frac{1}{4}\times 2\\ &= \frac{1.58}{3}+\frac{2.58}{6}+\frac{1}{2}+\frac{1}{2}\\ &= 1.956 \cong 2 \text{ bits/symbol}\end{aligned}$$

**68. (d)**

The entropy of the source is

$$\begin{aligned}H(s) &= \frac{1}{2}\log_2(2)+\frac{1}{4}\log_2(4)+\frac{1}{4}\log_2(4)\\ &= \frac{1}{2}\times 1+\frac{1}{4}\times 2+\frac{1}{4}\times 2=\frac{3}{2}\text{ bits/symbol}\end{aligned}$$

The entropy of second order extension of the source is

$$H(s^2) = 2 \times H(s) = 2\times\frac{3}{2}=3\text{ bits/symbol}$$

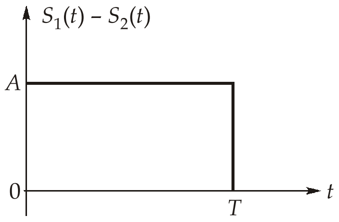
**69. (b)**

For a binary signalling scheme with additive white gaussian noise, probability of error is given by

$$P_e = Q\left(\sqrt{\frac{E_d}{2N_0}}\right)$$

where

$$E_d = \int_0^T [S_1(t)-S_2(t)]^2\,dt$$



$$E_d = \int_0^T A^2 dt = A^2T$$

We have,

$$P_e = Q\left(\sqrt{\frac{A^2T}{2N_0}}\right) = 10^{-5}$$

$$Q(4.25) = Q\left(\sqrt{\frac{A^2T}{2N_0}}\right)$$

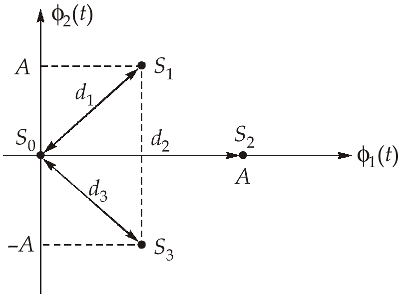
$$\sqrt{\frac{A^2T}{2N_0}} = 4.25$$

Given, $R_b = 10^5$ bps $\Rightarrow$ $T = 10^{-5}$s

$N_0 = 10^{-7}$ W/Hz

$\therefore$ $$A = \sqrt{\frac{(4.25)^2\times 2\times 10^{-7}}{10^{-5}}} = 0.6$$

**70.** **(c)**



Let the energy associated with the symbols $S_0$, $S_1$, $S_2$ and $S_3$ are $E_0$, $E_1$, $E_2$ and $E_3$ respectively. The energy of a symbol represented by a point in a constellation diagram, is equal to the square of the distance of that point from the origin. Thus,

$$E_i = (d_i)^2; \quad i = 0, 1, 2, 3$$

From the above diagram,

$$d_0 = 0$$

$$d_1 = d_3 = \sqrt{\left(\frac{A}{2}\right)^2 + A^2} = \sqrt{\frac{A^2}{4} + A^2} = \frac{\sqrt{5}}{2}A$$

$$d_2 = A$$

So, $$E_0 = 0$$

$$E_1 = E_3 = \frac{5}{4}A^2$$

$$E_2 = A^2$$

The average symbol energy of the modulation scheme can be given as,

$$E_s = \sum_{i=0}^{3} E_i P(S_i)\ ;\ P(S_i) = \text{Probability of the symbol } S_i$$

$$= 0\times\frac{1}{10} + \frac{5}{4}A^2\times\frac{1}{5} + A^2\times\frac{1}{2.5} + \frac{5}{4}A^2\times 0.3$$

$$= \frac{A^2}{4} + 0.4A^2 + 0.375A^2$$

$$= 0.25A^2 + 0.4A^2 + 0.375A^2$$

$$= 1.025A^2 \cong A^2$$

**71. (b)**

Efficiency (η) of data transmission is given by:

$$\eta = \frac{H(X)}{H_{\max}(X)}$$

where $H(X)$ is the entropy of the source and $H_{\max}(X)$ is the maximum entropy of the source. Adding redundancy to the source, causes the entropy to reduce to $H'(X)=0.8\ H(X)$. Hence,

$$\eta' = \frac{0.8H(X)}{H_{\max}(X)} = 0.8\eta$$

Thus, the efficiency of data transmission decreases by 20%.

**72. (c)**

Shannon's noisy channel coding theorem states that for a noisy channel with a capacity $C$, it is possible to achieve error-free transmission of data if the transmission rate $R$ (in bits per second) is less than or equal to the channel capacity $C$. This is achieved by using suitable error-correcting codes.

**73. (c)**

- DPCM encodes the difference between consecutive samples which reduces redundancy, especially for signals with high correlation (e.g. audio or speech signals).
- DM uses a fixed step size for quantization, resulting in granular noise for small signal variations and slope overload distortion for steep signals variations.
- ADM dynamically adjusts the step size based on the slope of the input signal, which allows it to handle both small and steep variations more effectively than DM.
- DPCM typically requires lower bit rates than PCM for the same fidelity because it transmits the difference values instead of absolute amplitudes, reducing the number of bits per sample.
- ADM's adaptive step size addresses both granular noise (by reducing the step size for low-slope signals) and slope overload distortion (by increasing the step size for high-slope signals)

**74. (c)**

- Redundancy introduces repetitive or predictable information that does not contribute to the source's effective information content. Efficient compression aims to minimize this redundancy. Thus, Redundancy in a source reduces the efficiency of data compression.
- Redundancy reduces the entropy of the source. Entropy represents the average uncertainty or information content, and redundant data decreases uncertainty, thereby lowering entropy. Hence, statement (II) is false.

**75. (a)**

- A raised cosine filter is widely used in digital communication to minimize inter-symbol interference (ISI) by shaping the spectrum of the transmitted signal. It ensures that the signal satisfies the Nyquist ISI criterion, which eliminates ISI by having zero inter-symbol interference at the sampling instants.
- The roll-off factor of the raised cosine filter determines the transition bandwidth outside the main lobe of the spectrum and thus, helps in reducing the ISI by selecting an appropriate value of roll-off factor.

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