DETAILED SOLUTIONS

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ESE 2026 : Prelims Exam
CLASSROOM TEST SERIES

E & T ENGINEERING

Test 8

Section A : Analog and Digital Communication Systems

Section B : Electronic Devices & Circuits-1 + Analog Circuits Topics-1

Section C : Control Systems-2 + Microprocessors and Microcontroller-2

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DETAILED EXPLANATIONS
Section A : Analog and Digital Communication Systems

1. (d)

Linear Modulation Techniques:

- Amplitude Modulation (AM)
- Quadrature Amplitude Modulation (QAM)
- Amplitude Shift Keying (ASK)
- Phase Shift Keying (PSK)
- Quadrature Phase Shift Keying (QPSK)
- Vestigial Sideband (VSB)

Non-Linear Modulation Techniques:

- Angle Modulation
- Pulse Modulation
  - → Pulse Width Modulation (PWM)
  - → Pulse Position Modulation (PPM)
  - → Pulse Frequency Modulation (PFM)
- Frequency-shift Keying (FSK)
- Gaussian Minimum-shift Keying (GMSK)

2. (b)

Given, the angle-modulated signal,

$$x_c(t) = A\cos\left(\omega t + \frac{\pi}{6}\right) = A_c\cos(\theta_i(t))$$

Instantaneous frequency:

$$f_i = \frac{1}{2\pi}\frac{d\theta_i(t)}{dt}$$

$$f_i = \frac{1}{2\pi}\frac{d\left[\left(\omega t + \frac{\pi}{6}\right)\right]}{dt}$$

We know,

$$\omega = 2\pi f$$

$\Rightarrow$

$$f_i = \frac{1}{2\pi}\frac{d}{dt}\left(2\pi f t + \frac{\pi}{6}\right)$$

$$f_i = \frac{1}{2\pi}[2\pi f]$$

$$f_i = f = 100 \text{ Hz}$$

$$\omega = 2\pi f \text{ rad/s}$$

$\Rightarrow$

$$\omega = 200\,\pi \text{ rad}$$

3. (a)

- In a block code, the minimum Hamming distance determines both error-detection and error-correction limits.
  d_{min} = minimum number of bits by which any two code words differ.
  Hence, statement 1 is correct.
- A code can detect upto (d_{min} – 1) error only.
  Therefore, statement 2 is correct.
- A code can correct a maximum of $\left[\dfrac{d_{min}-1}{2}\right]$ errors.
- For d_{min} = 7:
  $t = \dfrac{7-1}{2} = 3$ it implies it can correct maximum of 3 errors.

4. (d)

Minimum sampling frequency:

$$f_{s\ min} = \frac{2f_H}{k} \text{ where } k = \left\lfloor \frac{f_H}{f_H - f_L} \right\rfloor$$

where $\lfloor x \rfloor$ means the greatest integer lower than x.

$$k = \left\lfloor \frac{2.75}{2.75-2} \right\rfloor = \left\lfloor \frac{2.75}{0.75} \right\rfloor$$

$$k = 3$$

$$f_{s\ min} = \frac{2\times 2.75}{3} = 1.83 \text{ MHz}$$

5. (d)

The entropy of the source is: $H(X) = \dfrac{1}{2}\log_2 2 + \dfrac{2}{4}\log_2 4 = 1.5$ bits/symbol

The entropy of the 3rd order extension of the source can be given as,

$$H(X^3) = 3H(X) = 3(1.5) \text{ bits/block} = 4.5 \text{ bits/block}$$

6. (a)

The bandwidth of the baseband signal with raised cosine pulse shaping is:

$$(\text{BW})_{\text{signal}} = \frac{R_b}{2}(1+\alpha) = \frac{100}{2}(1+\alpha) = 50(1+\alpha) \text{ kHz}$$

For proper transmission of the data:

$$(\text{BW})_{\text{signal}} \le (\text{BW})_{\text{channel}}$$

$$50(1+\alpha) \le 80$$

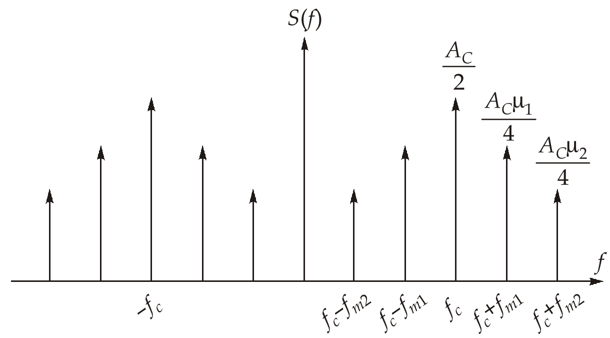
$$1+\alpha \le 1.60$$

$$\alpha \le 0.60$$

Thus, $\alpha_{max} = 0.60$

7. (c)

The frequency spectrum of multi-tone AM signal is



on comparing, $\frac{A_C}{2} = 5;\ \frac{A_C\mu_1}{4} = 2;\ \frac{A_C\mu_2}{4} = 1.5$

∴ $A_C = 10\text{ V}$

$$\mu_1 = \frac{8}{A_C} = \frac{8}{10} = 0.8$$

$$\mu_2 = \frac{6}{A_C} = \frac{6}{10} = 0.6$$

∴ the modulation index of multi-tone AM signal is,

$$\mu_t = \sqrt{\mu_1^2 + \mu_2^2} = \sqrt{(0.6)^2 + (0.8)^2} = 1$$

total power, $P_T = P_C\left[1 + \frac{\mu_t^2}{2}\right] = P_C\left[1 + \frac{1}{2}\right] = \frac{A_C^2}{2}\left[\frac{3}{2}\right] = \frac{100 \times 3}{4}$

∴ $P_t = 75\text{ W}$

8. (c)

The transmission efficiency of an AM signal is given by:

$$\eta = \frac{k_a^2 P_m}{1 + k_a^2 P_m}$$

where, k_a = amplitude sensitivity of the AM modulator

P_m = average power of the message signal $m(t)$

With $m_1(t)$ as the message signal:

$$P_m = \frac{1}{T}\left[\int_0^{T/2} (A)^2 dt + \int_{T/2}^{T} (-A)^2 \cdot dt\right]$$

$$= \frac{1}{T}\left[A^2 \times \frac{T}{2} + A^2 \times \frac{T}{2}\right]$$

$$= \frac{1}{T}\left[A^2 \times T\right] = A^2$$

So, $$\eta_1 = \frac{k_a^2 A^2/2}{1 + k_a^2 A^2/2} = \frac{k_a^2 A^2}{2 + k_a^2 A^2} \quad \text{...(i)}$$

With $m_2(t)$ as the message signal:

$$P_m = \frac{1}{T}\int_0^T A^2 dt = A^2$$

$$\eta_2 = \frac{k_a^2 A^2}{1+k_a^2 A^2} \quad \text{...(ii)}$$

From equations (i) and (ii), it is clear that,

$$\eta_1 < \eta_2$$

9. (c)

We have,

Carrier power, P_c = 400 W

Modulation index, μ = 1 (for 100% modulation)

$$\text{Total transmitted power: } P_t = P_c\left[1+\frac{\mu^2}{2}\right]$$

$$\Rightarrow \quad 600 = P_c\left[1+\frac{1}{2}\right] \Rightarrow P_c = 400 \text{ W}$$

With new modulation index, μ_1 = 0.5,

$$\text{Total transmitted power, } P_t = 400\left[1+\frac{0.5^2}{2}\right]$$

$$P_t = 450 \text{ Watt}$$

10. (d)

We have, Carrier frequency, f_c = 100 MHz

Message signal frequency, f_m = 5 kHz

Frequency deviation, Δf = 75 kHz

We know that,

$$\text{Modulation index: } \beta_{FM} = \frac{\Delta f}{f_m}$$

$$\beta_{FM} = \frac{75\times 10^3}{5\times 10^3} = 15$$

Bandwidth (Carson's Rule): BW = $2(\beta + 1)f_m$

BW = $2[15 + 1] \times 5 \times 10^3$

BW = 160 kHz

11. (a)

In the locked condition,

$$\frac{f_o}{3} = f_i$$

$$f_i = \frac{15}{3} = 5 \text{ kHz}$$

12. **(c)**

- VSB : Used in TV picture transmission.
- DSB-SC : Double-side band suppressed carrier (No carrier, both sidebands)
- SSB : Only one sideband transmitted
- FM : Constant envelope modulation

13. **(a)**

We have,

$$\text{Message frequency, } f_m = 3 \text{ kHz}$$

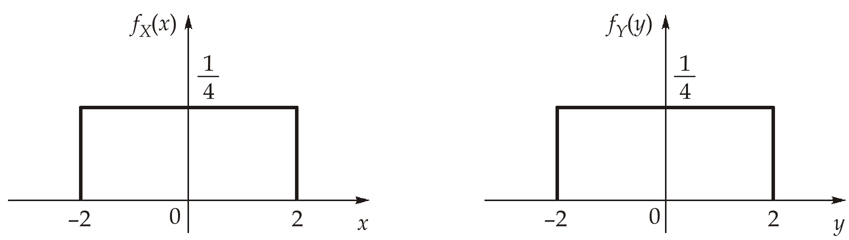
$$\text{Maximum frequency deviation, } \Delta f = 15 \text{ kHz}$$

$$\text{Modulation index, } \beta = \frac{\Delta f}{f_m} = \frac{15}{3} = 5$$

$$\text{Significant sidebands} \approx \beta + 1 = 5 + 1 = 6 \text{ pairs}$$

14. **(b)**

The PDFs of X and Y are:



max[X, Y] will be less than 1, if both X and Y are less than 1.

So, the required probability is, $P = P(X < 1) \times P(Y < 1)$

$$= \int_{-2}^{1} f_X(x)dx \times \int_{-2}^{1} f_Y(y)dy$$

$$= \int_{-2}^{1} \frac{1}{4} dx \times \int_{-2}^{1} \frac{1}{4} dy$$

$$= \left[\frac{1}{4}(1+2)\right]^2 = \left(\frac{3}{4}\right)^2$$

$$= \frac{9}{16}$$

15. **(d)**

- As, $\text{Bandwidth, BW} = 2(\beta + 1)f_m$

$$= 2\left(\frac{\Delta f}{f_m} + 1\right) f_m$$

$$\text{BW} = 2(\Delta f + f_m)$$

$$\text{BW} \propto \Delta f$$

- For wideband FM, $\beta >> 1$.
- Narrowband FM behaves similar to PM.

16. (c)

We know that, th total area under a probability density function (PDF) is always equal to 1.

$$\int_0^2 kx\,dx = \left.\frac{kx^2}{2}\right|_0^2 = 1$$

$$k\left[\frac{2^2-0}{2}\right] = 1$$

$$k = \frac{1}{2}$$

Now,
$$E[X] = \int_0^2 xf(x)dx$$

$$E[X] = \int_0^2 x(kx)dx$$

$$E[X] = k\int_0^2 x^2 dx = k\left[\left.\frac{x^3}{3}\right|_0^2\right]$$

$$E[X] = k\left[\frac{8}{3}\right] = \frac{8}{3}\times\frac{1}{2} = \frac{4}{3}$$

17. (d)

- An ergodic process is a stationary process where time averages are equal to ensemble averages. A stationary process's statiscal properties, such as its mean, variance, and probability distribution, are constant over time.
- A Gaussian process (GP) is fully described by its mean function and its covariance-function (also known as the kernel function).
- White Noise has a constant or flat power spectral density across all frequencies.

18. (d)

- $\eta_{AM} = \dfrac{\mu^2 P_{mn}}{1+\mu^2 P_{mn}}$; where, $P_{mn} = \dfrac{\text{Power of message signal } m(t)}{|m(t)|^2_{\max}}$
- $\eta_{AM} = \dfrac{k_a^2 P_m}{1+k_a^2 P_m}$; where, P_m = Power of message signal $m(t)$
- $\eta_{AM} = \left[1-\dfrac{2}{\mu^2+2}\right] = \dfrac{\mu^2}{\mu^2+2}$; when signal $m(t)$ is sinusoidal signal.

19. (a)

An envelope detector is also known as a **peak detector**, **diode detector**, **non-synchronous detector,** and **non-coherent detector**. A synchronous detector is known as a Coherent detector.

20. **(b)**

We have,

$$\text{Maximum amplitude peak, } A_{max} = A_c(1 + \mu) = 9 \text{ V}$$

$$\text{Carrier voltage, } A_c = 5 \text{ volt}$$

$$9 = 5(1 + \mu)$$

$$1 + \mu = \frac{9}{5}$$

$$\mu = \frac{4}{5} = 0.8$$

Now,

$$A_{min} = A_c(1 - \mu)$$

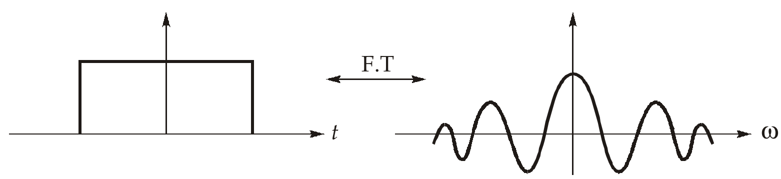
$$A_{min} = 5(1 - 0.8)$$

$$= 5 \times 0.2$$

$$= 1 \text{ volt}$$

21. **(c)**

The Fourier transform of a rectangular function is a sinc function, hence the covariance function of band-limited white noise is a sinc function.



22. **(c)**

$$H(L) = P_0 \log_2\left(\frac{1}{P_0}\right) + P_1 \log_2\left(\frac{1}{P_1}\right) + P_2 \log_2\left(\frac{1}{P_2}\right)$$

$$= \frac{1}{4}\log_2(4) + \frac{1}{4}\log_2(4) + \frac{1}{2}\log_2(2)$$

$$= \frac{1}{4}(2) + \frac{1}{4}(2) + \frac{1}{2}(1)$$

$$= \frac{3}{2} \text{bits} = 1.5 \text{ bits}$$

23. **(c)**

Image frequency is given by,

$$f_{si} = f_s + 2IF \qquad \text{if } f_{LO} > f_s$$

$$f_{si} = f_s - 2IF \qquad \text{if } f_{LO} < f_s$$

Given,

$$f_{LO} = 4 \text{ GHz;}$$

$$\text{Intermediate frequency, } I_F = 10 \text{ MHz}$$

$$f_s - f_{LO} = IF$$

$\Rightarrow$

$$f_s = f_{LO} + IF$$

$$= 4000 + 10$$

$\therefore$

$$f_s = 4010 \text{ MHz}$$

Clearly, $f_{LO} < f_s$

∴ Image frequency, $f_{si} = f_s - 2IF$

$$f_{si} = 4010 - 2 \times 10 = 3990 \text{ MHz}$$

24. (c)

- Shannon capacity for an AWGN is given by

$$C = B\log_2\left(1+\frac{S}{N}\right)$$

Therefore, statement 1 is correct.

- For a fixed total signal power S, increasing B reduces noise power per Hz (Since noise αB). Thus, increasing bandwidth does not always increase capacity without limit-capacity approaches a finite value:

$$C_{max} = \frac{S}{N_0(\ln 2)} = 1.44\frac{S}{N_0}$$

So, statement 2 is false.

- For fixed S and Noise spectral density N_0, if $B \to \infty$ then

$$C = 1.44\left[\frac{S}{N_0}\right]$$

Therefore statement 3 is true.

25. (a)

We have, Carrier frequency, $f_c = 10^6$ Hz

Frequency deviation constant, $k_f = 5$ Hz/V

For a frequency-modulated signal, the instantaneous frequency (f_i) is given as

$$f_i = f_c + k_f m_1(t)$$

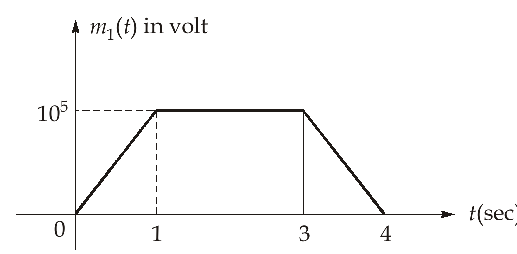
f_i will be maximum when $m_1(t)$ is maximum.

$$m_1(t)\big|_{max} = 10^5 \text{ V}$$

Therefore, $f_{i\,max} = f_c + k_f m(t)\big|_{max}$

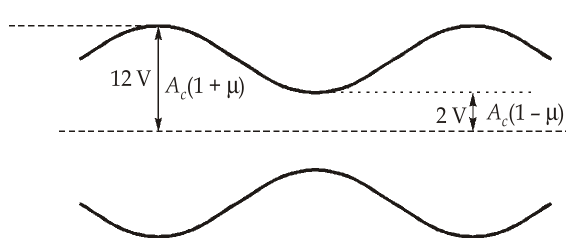
$$= 10^6 + 5 \times 10^5$$

$$= 1.5 \text{ MHz}$$



26. (c)

The envelope of an under modulated AM signal with peak amplitude of a sinusoidal carrier, A_c and modulation index, μ is shown below:



On comparing, we get

$$A_c(1+\mu) = 12$$
$$A_c(1-\mu) = 2$$

Dividing the two equations:

$$\frac{1+\mu}{1-\mu} = 6$$
$$1+\mu = 6-6\mu$$
$$7\mu = 5$$
$$\mu = \frac{5}{7}$$

Now,
$$A_c\left(1+\frac{5}{7}\right) = 12$$
$$A_c \times \frac{12}{7} = 12$$
$$A_c = 7 \text{ volt}$$

The total sideband power, $P_{SB} = \frac{A_c^2\mu^2}{4} = \frac{(7)^2 \times \left(\frac{5}{7}\right)^2}{4}$

$$P_{SB} = \frac{25}{4} = 6.25 \text{ Watt}$$

27. (a)

SNR of a delta modulator,

$$\text{SNR} = \frac{3}{8\pi^2}\left(\frac{f_s}{f_m}\right)^3$$

$\because$ Bit rate, $R_b = 2\pi$ kbps

Since for delta modulation:

$$R_b = nf_s = 2\pi \text{ kbps; where } n = 1$$
$$1 \times f_s = 2\pi \text{ kbps}$$
$$f_s = 2\pi \text{ kHz}$$

Given: $f_m = 4$ kHz

$\therefore$
$$\text{SNR} = \frac{3}{8\pi^2}\left(\frac{2\pi}{4}\right)^3 = \frac{3}{8\pi^2} \times \frac{8\pi^3}{64}$$
$$\text{SNR} = \frac{3\pi}{64}$$

$\therefore$
$$\text{SNR in dB} = 10\log\left(\frac{3\pi}{64}\right) = -8.32 \text{ dB}$$

28. (b)

The sampling theorem states that if the highest frequency in the signal spectrum is B (in Hz), the signal can be reconstructed if sampled at a rate not less than 2B samples per second.

29. (c)

Slope overload occurs in DM when the rate of change of the analog waveform is too large.

$$\left|\frac{dm(t)}{dt}\right| > \left(\frac{\Delta}{T_s}\right)$$

$$\underset{\text{Rate of change of message signal}}{\downarrow} > \underset{\text{slope at output of pulse code modulator}}{\downarrow}$$

In TDM, pulses from different sources are separated from each other in the time domain.

The ability of an FM receiver to lock onto a stronger signal and thereby suppress a weaker signal of the same frequency is known as the capture effect.

30. (d)

Average power of an angle-modulated signal $x(t) = \frac{A_c^2}{2}$. Here, $A_c = 4$ V

$$\therefore \quad \text{Average power} = \frac{(4)^2}{2} = \frac{16}{2} = 8 \text{ W}$$

31. (d)

The capacity of an AWGN channel, with bandwidth B can be given by,

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

We have,

$$\text{Bandwidth, } B = 300 \text{ kHz}$$

$$10 \log_2\text{SNR} = 15 \text{ dB}$$

$$\text{SNR} = 10^{1.5} \approx 31.62$$

$$C = 300 \log_2(1 + 31.62)$$

$$C \approx 1500 \text{ kbps}$$

32. (d)

We have,

$$\text{Bit rate, } R_b = 64 \text{ Mbps}$$

$$\text{Number of bits, } n = 8$$

$$\therefore \quad R_b = nf_s$$

$$64 \times 10^6 = 8f_s$$

$$f_s = 8 \text{ MHz}$$

According to the sampling theorem:

$$f_s \geq 2f_m$$

$$8 \text{ MHz} \geq 2f_m$$

$$4 \text{ MHz} \geq f_m$$

$$f_m = 4 \text{ MHz}$$

33. (c)

In SSB, both sidebands carry the same information, but only one sideband is transmitted, not both.

34. (c)

To avoid slope-overload error, the condition is

$$\left.\frac{dm(t)}{dt}\right|_{\max} \le \frac{\Delta}{T_s}$$

35. (a)

FM is immune to amplitude variations; limiters improve SNR.

36. (c)

Video signals do not have negligible power at lower frequencies.

37. (c)

Pre-emphasis is used in the transmitter, and de-emphasis is used in the receiver of FM systems.

38. (a)

FM is less susceptible to noise because it encodes information in the frequency of the carrier wave, not its amplitude.

Section B : Electronic Devices & Circuits-1 + Analog Circuits Topics-1

39. (c)

Given, $P_{in} = 60\ \mu W$

$A_v = 132,\ \beta = 200$

Power gain of the amplifier, $A_p = A_v \times \beta$

$= 132 \times 200 = 26400$

But $A_p = \frac{P_{out}}{P_{in}}$

$\therefore$ Output power, $P_{out} = A_p \times P_{in}$

$= 26400 \times 60 \times 10^{-6}$

$\therefore$ $P_{out} = 1.584\ W$

40. (c)

From the given small signal A.C equivalent circuit,

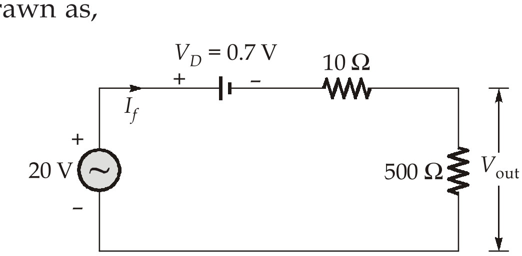
Peak input voltage, $V_p = 20\ V$

Forward resistance, $R_f = 10\ \Omega$

Load resistance, $R_L = 500\ \Omega$

Forward voltage, $V_0 = 0.7\ V$

The equivalent circuit is drawn as,



Peak output voltage, $V_p' = I_f \times R_L$

where, $I_f = \dfrac{20-0.7}{10+500} = 37.8 \text{ mA}$

$\therefore$ $V'_p = 37.8 \times 10^{-3} \times 500$

$\therefore$ $V'_p = 18.9 \text{ V}$

41. (a)

The common-gate amplifier is often used as a high-frequency amplifier.

42. (b)

Given, $V_{GS} = -2 \text{ V}$

From the graph, $g_m\big|_{V_{GS}=0} = g_{m0} = 20 \times 10^{-3}$ ℧

$V_p = -4 \text{ V}$

$\therefore$
$$g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right]$$
$$= 20\times10^{-3}\left[1 - \frac{-2}{-4}\right]$$

$g_m = 10 \times 10^{-3}$ ℧ (or) 0.01 ℧

43. (d)

Given, $\dfrac{V_m}{2} = 230$

$V_m = 2 \times 230 = 460 \text{ V}$

$\therefore$ DC output voltage, $V_{DC} = V_m - \dfrac{V_r}{2}$

where, ripple voltage, $V_r = \dfrac{V_{DC}\times T_0}{R_L C}$

$\therefore$
$$V_r = \frac{V_m \times T_0}{\pi\times R_L C} = \frac{460\times\frac{1}{50}}{\pi\times 0.4} = 7.32 \text{ V}$$

$\therefore$
$$V_{DC} = 460 - \frac{7.32}{2} = 456.33 \text{ V}$$

Ripple factor for a halfwave rectifier with a capacitive filter:

$$r = \frac{1}{2\sqrt{3} f_0 R_L C}$$

$$r = \frac{1}{2\sqrt{3}\times 50\times 200\times 2000\times 10^{-6}} = 0.014$$

44. (d)

Given, $h_{oe} = 10 \times 10^{-6}$ ℧; $R_L = 5 \text{ k}\Omega$

$\therefore$ $h_{oe} \times R_L = 10 \times 10^{-6} \times 5 \times 10^3 = 0.05 < 0.1$

Hence, approximate analysis can be used.

$$A_I = -h_{fe} = -50$$

$$\text{Voltage gain, } A_V = \frac{-h_{fe} \times R_L}{h_{ie}} = \frac{-50 \times 5}{1} = -250$$

$$\text{Power gain, } A_P = A_V \times A_I = 50 \times 250 = 12500$$

45. **(d)**

Given,
$$D_p = 15 \text{ cm}^2/\text{s}$$
$$I_D = 0.52 \text{ mA}$$

For P-type silicon:
$$I_D = -q(D_p \times \text{Area})\frac{dp}{dx}$$

$\therefore$
$$\frac{dp}{dx} = \frac{I_D}{-qD_pA} = \frac{0.52 \times 10^{-3}}{-1.6 \times 10^{-19} \times 15 \times 1}$$

$\therefore$
$$\frac{dp}{dx} = -2.17 \times 10^{14} \text{ holes/cm}^4$$

46. **(d)**

For a compensated p-type semiconductor, the minority carrier electron concentation (n_0) is given by,

$$n_0 = \frac{n_i^2}{N_A - N_D},$$

where, 'n_i' is the intrinsic carrier concentation.
N_A is the acceptor concentration.
N_D is the donor concentration.

47. **(a)**

The density of allowed energy states in the conduction band is:

$$g_c(E) = \frac{4\pi(2m_n^*)^{3/2}}{h^3}\sqrt{E - E_c}$$

The density of allowed energy states in the valence band is:

$$g_v(E) = \frac{4\pi(2m_p^*)^{3/2}}{h^3}\sqrt{E_v - E}$$

Thus,
$$g_c(E) \propto \sqrt{E - E_c}\ ;\ g_v(E) \propto \sqrt{E_v - E}$$

$\therefore$ The option (a) satisfies the relation.

48. **(d)**

Given,
$$I_L = 10\ \mu\text{A}$$
$$\beta = 49$$

Since the base is open-circuited for a photo-transistor,

$$I_C = I_E = (1 + \beta)I_L$$

$\therefore$
$$I_C = (1 + 49)10\ \mu\text{A}$$
$$= 500\ \mu\text{A}$$

49. (c)

Given,

$$\text{Area, } A = 10^{-7}\ \text{cm}^2$$
$$L = 100\ \mu\text{m}$$
$$\tau_p = 10^{-6}\ \text{s}$$
$$V = 10\ \text{volts}$$

$$\text{Electron transit time, } t_n = \frac{L}{\mu_n E}$$

but $$E = \frac{V}{L}$$

$\therefore$ $$\text{Substituting, } t_n = \frac{L^2}{\mu_n \times V} = \frac{(100\times 10^{-4})^2}{1350\times 10}$$
$$t_n = 7.41 \times 10^{-9}\ \text{sec}$$

50. (b)

Given,

$$V_R = -12\ \text{V}$$
$$V_{bi} = 0.65\ \text{V}$$
$$W = 1.2\ \mu\text{m}$$

$\therefore$ $$\text{Maximum electric field, } E_{max} = \frac{-2(V_{bi}+V_R)}{W}$$
$$E_{max} = \frac{-2(0.65-12)}{1.2\times 10^{-6}}$$
$$= 18.9 \times 10^6\ \text{V/m}$$

51. (a)

Given,

$$I_C = 1.5\ \text{mA}$$
$$I_{CEO} = 2.5\ \mu\text{A}$$
$$\beta = 50$$

$$\text{Base current, } I_B = \frac{I_C - I_{CEO}}{\beta} = \frac{(1.5\times 10^{-3} - 2.5\times 10^{-6})}{50}$$

$\therefore$ $$I_B = 3 \times 10^{-5}\ \text{A} \quad \text{(or)} \quad 30\ \mu\text{A}$$
$$\text{Emitter current, } I_E = I_C + I_B$$
$$= 1.5 \times 10^{-3} + 0.03 \times 10^{-3}$$
$$I_E = 1.53\ \text{mA}$$

52. (a)

53. (c)

By using a bleeder resistance in the rectifier filter, the performance of voltage regulation is improved, not degraded.

54. (c)

Statement (II) is incorrect.

In semiconductors, the absorption coefficient increases with incident photon energy.

55. (c)

The reverse saturation current is due to the thermal generation of electron-hole pairs in **depletion regions**. Therefore Statement (II) is incorrect.

Section C : Control Systems-2 + Microprocessors and Microcontroller-2

56. (a)

For given state model,

$$A = \begin{bmatrix} -4 & 0 \\ 0 & -3 \end{bmatrix}$$

$$[sI - A] = \begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} - \begin{bmatrix} -4 & 0 \\ 0 & -3 \end{bmatrix} = \begin{bmatrix} s+4 & 0 \\ 0 & s+3 \end{bmatrix}$$

$$[sI - A]^{-1} = \frac{1}{|sI - A|}\text{Adj}[sI - A] = \frac{1}{(s+3)(s+4)}\begin{bmatrix} s+3 & 0 \\ 0 & s+4 \end{bmatrix}$$

$$= \begin{bmatrix} \frac{1}{s+4} & 0 \\ 0 & \frac{1}{s+3} \end{bmatrix}$$

$$\therefore \quad L^{-1}[sI - A]^{-1} = e^{At} = \begin{bmatrix} e^{-4t} & 0 \\ 0 & e^{-3t} \end{bmatrix}$$

So zero-input response of the given system will be

$$x(t) = e^{At} \cdot x(0)$$

$$= \begin{bmatrix} e^{-4t} & 0 \\ 0 & e^{-3t} \end{bmatrix}\begin{bmatrix} 4 \\ -4 \end{bmatrix} = \begin{bmatrix} 4e^{-4t} \\ -4e^{-3t} \end{bmatrix}$$

57. (d)

We can analyze from the given transfer function that the zero lies closer to the origin than the pole, so it is a lead compensator.

Comparing with the standard form:

$$\text{Transfer function, } C(s) = \frac{4s+1}{0.4s+1} = \frac{1+Ts}{1+\alpha Ts}$$

$$T = 4,$$

$$\alpha T = 0.4$$

$$\alpha \times 4 = 0.4$$

$$\alpha = \frac{0.4}{4} = 0.1$$

A lead compensator in a closed-loop system increases the bandwidth and therefore leads to a faster time response.

58. (c)

Given, $$G(s) = \frac{K}{s(1+0.4s)(1+0.05s)}$$

Putting $s = j\omega$:

$$G(j\omega) = \frac{K}{(j\omega)(1+0.4j\omega)(1+0.05j\omega)}$$

$$G(j\omega) = \frac{K}{-0.45\omega^2 + j\omega(1-0.02\omega^2)}$$

At the phase cross over frequency (ω_p), the value of $G(j\omega)$ is purely real

∴ Equating the imaginary part to zero

$$\omega_p(1 - 0.02\,\omega_p^2) = 0$$

$$\omega_p^2 = \frac{1}{0.02} = 50$$

$$\omega_p = 0 \text{ and } \omega_p = \sqrt{50} \text{ rad/sec}$$

Note:

(Important shortcut method for calculating ω_p in standard form $\frac{K}{s(1+sT_1)(1+sT_2)}$)

Phase cross over frequency, $$\omega_p = \frac{1}{\sqrt{T_1T_2}}$$

$$= \frac{1}{\sqrt{0.4\times 0.05}} = \sqrt{50} \text{ rad/sec}$$

$$|G(j\omega)|_{\omega=\omega_p} = \frac{K}{0.45\omega_p^2} = \frac{K}{0.45\times 50} = \frac{K}{22.5}$$

Using gain margin requirement

Given: $$20\log(\text{GM}) = 40 \text{ dB}$$

$$\log(\text{GM}) = 2$$

$$\text{GM} = 100$$

∴ $$a = \frac{1}{GM} = \frac{1}{100} = 0.01$$

$$\frac{K}{22.5} = 0.01$$

$$K = 0.225$$

59. (b)

The frequency at which open loop transfer function of the system gives $|G(j\omega)\,H(j\omega)| = 1$ is called the gain crossover frequency.

60. (c)

We know: $$G(s)H(s) = \frac{K}{(1+s\tau)}$$

Given: $20 \log K = 40$

$\log K = 2$

$K = 100$

and the corner frequency is, $\omega = 1$ rad/sec

Thus, $$G(s)H(s) = \frac{100}{s+1}$$

Since, $H(s) = 1$

Closed-loop transfer function:

$$\frac{G(s)}{1+G(s)} = \frac{100}{s+101}$$

61. (a)

Given, Transfer function, $$G(s) = \frac{1}{s^2(1+s)(1+2s)}$$

Putting, $s = j\omega$

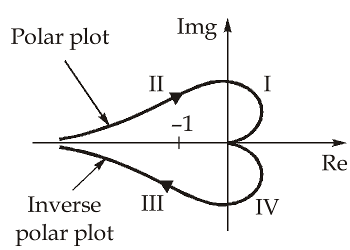
$$G(j\omega) = \frac{1}{(j\omega)^2(1+j\omega)(1+2j\omega)} = \frac{-1-(-2\omega^2)+3j\omega}{\omega^2(1+\omega^2)(1+4\omega^2)}$$

At $\omega = 0$, $G(j\omega) = -\infty + j\infty$

At $\omega = \infty$, $G(j\omega) = 0 + j0$

∴ The polar plot does not cross the real axis.

The polar plot and inverse polar plot are shown below:



The inverse polar plot starts in the fourth quadrant and ends in the third quadrant. The plot encircles –1, hence it is unstable system.

62. (c)

Given open loop transfer function:

$$G(s) = \frac{1}{s(2s+1)(s+1)}, \quad H(s) = 1$$

So, $$G(s)H(s) = \frac{1}{s(2s+1)(s+1)}$$

By putting, $s = j\omega$

$$G(j\omega)\, H(j\omega) = \frac{1}{(j\omega)(2j\omega+1)(j\omega+1)}$$

The intersection with the real axis occurs in the negative half of the $j\omega$-plane, when the imaginary part of $G(j\omega)H(j\omega)$ is zero:

$$\therefore \quad \text{Im}\left\{\frac{(+1-2j\omega)(+1-j\omega)(-j\omega)}{\omega^2(4\omega^2+1)(1+\omega^2)}\right\} = 0$$

$$\text{Im}\{(\omega - 2\omega^3)j - (\omega^2 + 2\omega^2)\} = 0$$

So, $$\omega(1 - 2\omega^2) = 0$$

$$\omega = 0, \text{ and } \omega = \frac{1}{\sqrt{2}}$$

$$\therefore \quad \text{Value } G(j\omega)H(j\omega)\Big|_{\omega=\frac{1}{\sqrt{2}}} = \frac{1}{\left(j\frac{1}{\sqrt{2}}\right)\left(2j\frac{1}{\sqrt{2}}+1\right)\left(j\frac{1}{\sqrt{2}}+1\right)} = \frac{1}{\frac{j^2}{2}-1} = \frac{1}{-\frac{3}{2}} = -\frac{2}{3}$$

Thus, the Nyquist plot intersects the real axis at : $\left(\frac{-2}{3}, 0\right)$

63. (d)

The standard transfer function of a phase-lead compensator is,

$$G(s) = \frac{\alpha(1+Ts)}{1+\alpha Ts}$$

By comparing $$\alpha T = 0.025$$

and $$T = 0.25$$

The frequency at which maximum phase lead occurs:

$$\omega_m = \sqrt{\frac{1}{\alpha T}\cdot\frac{1}{T}} = \sqrt{\frac{1}{0.025}\times\frac{1}{0.25}} = \sqrt{40\times 4} = 4\sqrt{10}\ \text{rad/sec}$$

64. (b)

$$PM = 180° + \angle G(j\omega)\big|_{\omega=\omega_{gc}}$$

Given $$PM = 60°$$

$$\Rightarrow \quad 60° = 180° - 90° + 180° - \tan^{-1}\left(\frac{K\omega_{gc}}{3}\right)$$

or $$\frac{K\omega_{gc}}{3} = \frac{1}{\sqrt{3}}$$

or $$\omega_{gc} = \frac{\sqrt{3}}{K} \quad \text{...(i)}$$

Using the magnitude condition, we get,

$$\frac{\sqrt{\left[K^2\left(\frac{\sqrt{3}}{K}\right)^2\right]+9}}{\frac{\sqrt{3}}{K}} = 1$$

or $$\sqrt{12} = \frac{\sqrt{3}}{K}$$

or $$K = \frac{\sqrt{3}}{\sqrt{12}} = \frac{1}{2}$$

65. (c)

- For a noise-free system, a PD compensator improves transient response more effectively (better damping and faster response) than a lead compensator.
  Therefore, S_1 is correct.
- A PI compensator eliminates steady-state error because of the integrator. A lag compensator only increases low-frequency gain and cannot fully remove steady-state error.
  So, PI is better for steady-state performance when stability remains acceptable.
  Hence, S_2 is also correct.

66. (a)

Statement 3 is incorrect because embedded systems typically do not require a hard disk.

67. (d)

68. (b)

69. (b)

A real-time clock (RTC) generates regular periodic interrupts (ticks). Once started, this timing device neither resets nor reloads with another value.

70. (c)

71. (d)

PSW selects register banks.

72. (d)

All the given features are related with Mode-0 of 8255.

73. (d)

To generate a square wave, the required condition is,

$$T_{clock} \leq T_{square\ wave}$$

To generate a square wave with a time period of 100 ns,

$$T_{clock} \leq 100 \text{ ns}$$

$$f_{clock} \geq \frac{10^9}{100} \text{Hz} = 10 \text{ MHz}$$

$$f_{clock} \geq 10 \text{ MHz} \quad \text{...(i)}$$

To generate a square wave with a period of 10 ms,

$$T_{clock} \leq 10 \text{ ms}$$

$$f_{clock} \geq \frac{1000}{10} = 100 \text{ Hz}$$

$$f_{\text{clock}} \geq 100 \text{ Hz} \quad \text{...(ii)}$$

From equations (i) and (ii), $f_{\text{clock}} \geq 10 \text{ MHz}$

$$f_{\text{clock(min)}} = 10 \text{ MHz}$$

Thus, the minimum required frequency is 10 MHz.

74. (b)

An embedded system must have a processor and memory.

75. (a)

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