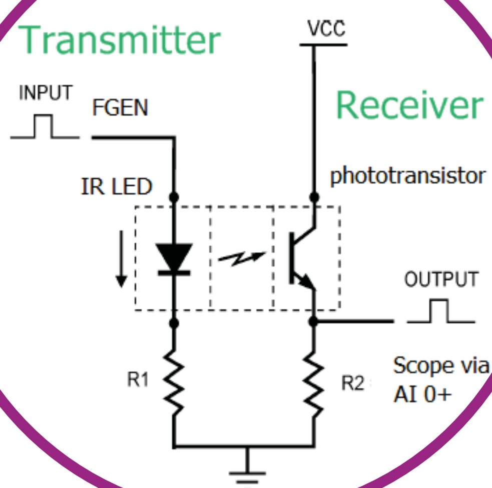
INSTRUMENTATION ENGINEERING



GATE | PSUs

COMMUNICATION &
OPTICAL INSTRUMENTATION

Volume - I : Study Material with Classroom Practice Questions

Classroom Practice Solutions
To
Communication & Optical Instrumentation

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Chapter **2**

Amplitude Modulation

Class Room Practice Solutions

01. Ans: (a)

Sol: $V(t) = A_c.\cos\omega_c t + 2\cos\omega_m t \,.\, \cos\omega_c t.$

Comparing this with the AM–DSB–SC signal

$A\cos\omega_c t + m(t).\cos\omega_c t$, it implies that

$m(t) = 2\cos\omega_m t \Rightarrow E_m = 2$

To implement Envelope detection,

$A_c \geq E_m$

$\therefore (A_c)_{min} = 2$

02. Ans (d)

Sol: $m(t) = (A_c + A_m\cos\omega_m t)\cos\omega_c t.$

$$= A_c(1 + \frac{A_m}{A_c}\cos\omega_m t)\cos\omega_c t.$$

Given

$A_c = 2A_m$

$$= A_c(1 + \frac{1}{2}\cos\omega_m t)\cos\omega_c t.$$

$$P_T = \frac{A_c^{\,2}}{2}\left[1+\frac{\mu^2}{2}\right],\ P_s = \frac{A_c^2}{2}\left[\frac{\mu^2}{4}\right]$$

$$\frac{P_T}{P_S} = \frac{1+\frac{\mu^2}{2}}{\frac{\mu^2}{4}} = \frac{1+\frac{1}{8}}{\frac{1}{16}} = \frac{9}{8}\times 16$$

$P_T = 18\,P_s$

03. Ans: (a)

Sol: $m(t) = 2\cos 2\pi f_1 t + \cos 2\pi f_2 t$

$C(t) = A_c\cos 2\pi f_c t$

$S(t) = [A_c + m(t)]\cos 2\pi f_c t$

$$S(t) = A_c[1 + \frac{1}{A_C}m(t)]\cos 2\pi f_c t$$

$$K_a = \frac{1}{A_c}$$

$A_{m1} = 2,\ A_{m2} = 1$

$$\mu_1 = K_a A_{m1} = \frac{2}{A_C},\ \mu_2 = K_a A_{m2} = \frac{1}{A_C}$$

$$\mu = \sqrt{\mu_1^2 + \mu_2^2}$$

$$\Rightarrow 0.5 = \sqrt{\frac{4}{A_c^2} + \frac{1}{A_c^2}}$$

$$\Rightarrow A_C = \sqrt{20}$$

04. Ans: (c)

Sol: $m(t) = -0.2 + 0.6\sin\omega_1 t,\ k_a = 1,\ A_c = 100$

$S(t) = A_c[1 - 0.2 + 0.6\sin\omega_1 t]\cos\omega_c t$

$= 100[0.8 + 0.6\sin\omega_1 t]\cos\omega_c t$

$V_{max} = A_c[1 + \mu] = 100[0.8 + 0.6] = 140\text{ V}$

$V_{min} = A_c[1 - \mu] = 100[0.8 - 0.6] = 20\text{ V}$

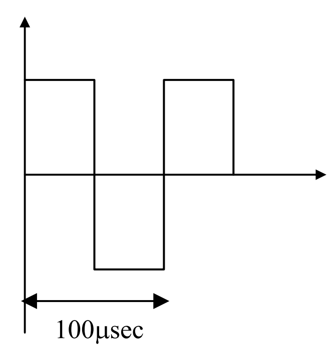
$= 20\text{V to } 140\text{ V}$

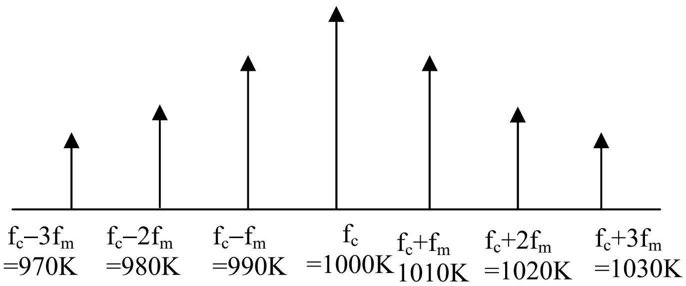
05. Ans: (c)

Sol: $f_C = 1\text{ MHz} = 1000\text{ kHz}$

The given m(t) is symmetrical square wave of period T = 100 μsec

$$f_m = \frac{1}{T_0} = 10\text{ kHz}$$



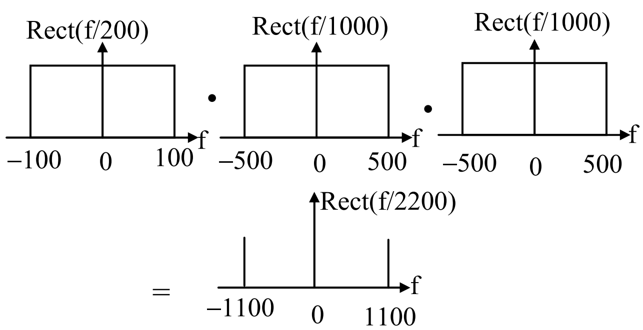


These frequencies 980k, 1020k are not present because the symmetrical square wave it consists of half wave symmetries only odd harmonics are present, even harmonics are dismissed

06. Ans: (d)

Sol: m(t) = sinc(200t)sinc^2(1000t)

= sinc(200t)sinc(1000t)sinc(1000t)

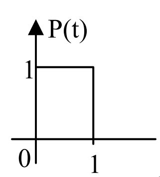


BW = 2 × 1100

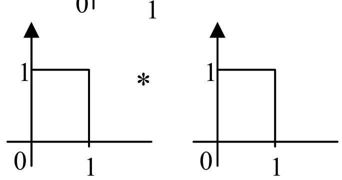
BW = 2200 Hz

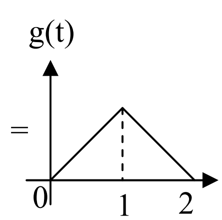
07. Ans: (a)

Sol: P(t) = u(t) –u(t–1) ⇒



g(t) = P(t) *P(t) =





$X(t) = 100(P(t) + 0.5g(t))\cos\omega_c t$

$= 100(1+0.5t)\cos\omega_c t$

$= A_c(1+K_a m(t))\cos\omega_c t$

$k_a = 0.5$, $m(t) = t$

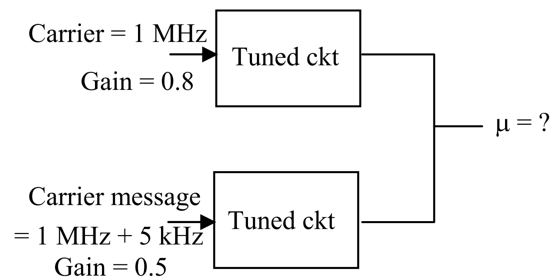
$\mu = k_a[m(t)]_{max}$

$\mu = 0.5 \times 1 = 0.5$

08. Ans: (d)

09. Ans (b)

Sol: $S(t) = 10\cos 2\pi 10^6 t + 8\cos 2\pi 5\times10^3 t \cos 2\pi 10^6 t$

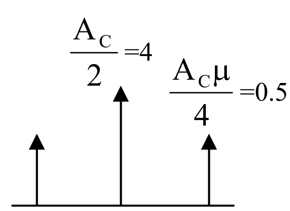


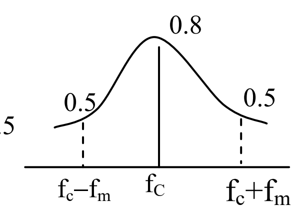
$S(t) = 0.8 \times 10\cos 2\pi 10^6 t$

$+ 0.5\times 8\cos 2\pi 5000t\cos 2\pi 10^6 t$

$= 8(1+\frac{4}{8}\cos 2\pi 5000t)\cos 2\pi 10^6 t$

$\mu = \frac{4}{8} = \frac{1}{2} = 0.5$





10. Ans: (d)

Sol: $A_{max} = 10V$

$A_{min} = 5V$

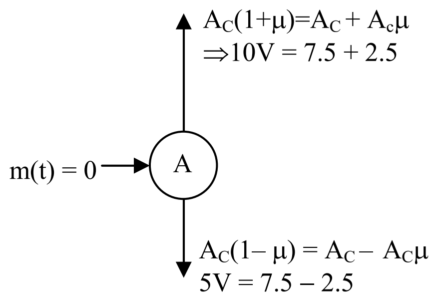
$\mu = 0.1$

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

$$= \frac{1}{3} = 0.33$$

$$A_C = \frac{A_{max} + A_{min}}{2}$$

$$= \frac{10+5}{2} = 7.5 \text{ V}$$



Amplitude deviation $A_C\mu = 7.5 \times \frac{1}{3} = 2.5$ V

$\mu_2 = 0.1 \Rightarrow A_{c2}\mu_2 = 2.5$

$A_{c2} = 25$ V

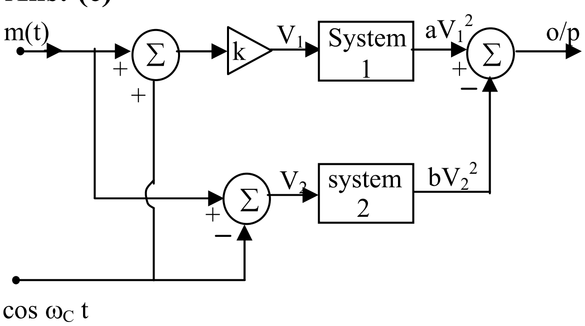
Which must be added to attain = 17.5

Chapter 3 Sideband Modulation Techniques

Class Room Practice Solutions

01. Ans: (c)

Sol:



$V_1 = k\,[m(t) + c(t)]$

$V_2 = [m(t) - c(t)]$

$V_0 = aV_1^2 - b\,V_2^2$

$= ak^2[m(t) + c(t)]^2 - b[m(t) - c(t)]^2$

$= ak^2\,[m^2(t) + c^2(t) + 2m(t)c(t)]$

$\quad - b[m^2(t) + c^2(t) - 2m(t)c(t)]$

$= [ak^2 - b]m^2(t) + [ak^2 - b]c^2(t)$

$\quad + 2[ak^2+b][m(t)c(t)]$

on verification if $k = \sqrt{\dfrac{b}{a}}$

$S(t) = 4bm(t)c(t) \rightarrow$ DSBSC Signal

02. Ans: (d)

Sol: Given A = 10

$m(t) = \cos 1000\pi t$

$b = 1$

B.W = ? and power = ?

$s(t) = 4b.A\cos 2\pi f_c t.\cos 2\pi\,(500)t$

$= 40.\cos 2\pi f_c t.\cos 2\pi\,(500)t$

$B.W = 2\,f_m$

$= 2\,(500) = 1\text{ kHz}$

$\text{Power} = \dfrac{A_c^2 A_m^2}{4}$

$= \dfrac{1600 \times 1}{4}$

$= 400\text{W}$

03. Ans: (c)

Sol: Carrier $= \cos 2\pi\,(100 \times 10^6)t$

Modulating signal $= \cos(2\pi \times 10^6)t$

Output of Balanced modulator

$= 0.5[\cos 2\pi\,(101 \times 10^6)t + \cos 2\pi(99\times10^6)t]$

The Output of HPF is $0.5\cos 2\pi(101 \times 10^6)t$

Output of the adder is

$= 0.5\cos 2\pi\,(101\times10^6)\,t + \sin 2\pi\,(100\times10^6)t$

$= 0.5\cos 2\pi[(100+1)10^6 t] + \sin 2\pi(100\times10^6)t$

$= 0.5[\cos 2\pi\,(100\times10^6)t.\cos 2\pi\,(10^6)t$

$\quad - \sin 2\pi(100 \times 10^6)t.\sin 2\pi\,(10^6)t]$

$\quad + \sin 2\pi(100\times10^6)t]$

$= 0.5\cos 2\pi\,(100\times10^6)t.\cos 2\pi\,(10^6)t$

$\quad + \sin 2\pi(100\times10^6)t\,[1-0.5\sin 2\pi\,(10^6)t]$

Let $0.5\cos 2\pi\,(10^6)t = r(t)\cos\theta(t)$

$1-0.5\sin 2\pi\,(10^6)t = r(t).\sin\theta(t)$

The envelope is

$r(t) = [\,0.25\cos^2 2\pi\,(10^6)t$

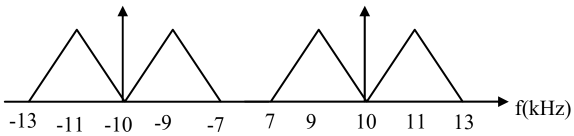
$\quad + \{1 - 0.5\sin 2\pi\,(10^6)t\}^2]^{1/2}$

$= [1.25 - \sin 2\pi(10^6)t]^{1/2}$

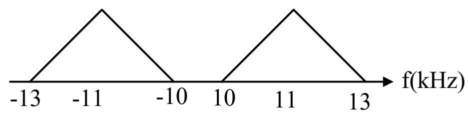
$= [\dfrac{5}{4} - \sin 2\pi\,(10^6)t]^{1/2}$

04. Ans: (b)

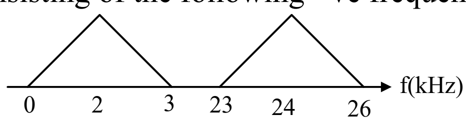
Sol: Output of 1st balanced modulator is



Output of HPF is



The Output of 2nd balanced modulator is consisting of the following +ve frequencies.



Thus, the spectral peaks occur at 2 kHz and 24 kHz

05. Ans: (c)

Sol: Given

$f_{m_1} = 100\text{Hz},\ f_{m_2} = 200\text{Hz},\ f_{m_3} = 400\text{Hz},$

$f_c = 100\text{KHz},\ f_{c_{L0}} = 100.02\text{KHz}$

$$S(t)/_{T_X} = \frac{A_c A_m}{2}[\cos(f_c + f_{m_1})t + \cos(f_c + f_{m_2})t + \cos(f_c + f_{m_3})t]$$

$$S(t)/R_x = [S(t)/T_x]A_c \cos 2\pi f_{c_{L0}} t$$

$$\Rightarrow \frac{A_c^2 A_m}{4}[\cos(f_c + f_{c_{Lo}} + f_{m_1}) + \cos(f_{m_1} - 20) + \cos(f_c + f_{c_{Lo}} + f_{m_2}) + \cos(f_{m_2} - 20) + \cos(f_c + f_{c_{Lo}} + f_{m_3}) + \cos(f_{m_3} - 20)]$$

Detector output frequencies:

80Hz, 180Hz, 380Hz

06. Ans: (b)

Sol: Given

SSB AM is used, LSB is transmitted

$f_{LO} = (f_c + 10)$

$$S(t)/T_X = \frac{A_c A_m}{2}\cos 2\pi[f_c - f_m]t$$

$$S(t)/R_X = \left[\frac{A_c A_m}{2}\cos 2\pi(f_c - f_m)t\right]\cos 2\pi(f_c + 10)t$$

$$\Rightarrow \frac{A_c A_m}{4}[\cos(2f_c + 10 - f_m)t + \cos(10 + f_m)t]$$

i.e., from 310 Hz to 1010 Hz

07. Ans: (b)

Sol: BW of Basic group = 12×4 = 48 kHz

BW of super group = 5×48 = 240 kHz

08. Ans: (d)

Sol: Given 11 voice signals

B.W. of each signals = 3 kHz

Guard Band Width = 1 kHz

Lowest f_c = 300 kHz

Highest f_c =

$$\Rightarrow f_{c_H} + f_{m_{lost}} = 300\text{kHz} + 11(3\text{kHz}) + 10(1\text{kHz}) = 343 \text{ kHz}$$

$$f_{c_H} = 343\,\text{kHz} - 3\,\text{kHz} = 340\,\text{kHz}$$

09. Ans: (b)

Sol: f_{m1} = 5 kHz → AM

f_{m2} = 10 kHz → DSB

f_{m3} = 10kHz → SSB

f_{m4} = 2kHz → SSB

f_{m5} = 5kHz → AM

f_g = 1kHz

$BW = (2f_{m1} + 2f_{m2} + f_{m3} + f_{m4} + 2f_{m5} + 4f_g)$

$= 2\times 5 + 2\times 10 + 10 + 2 + 2\times 5 + 4\times 1$

$= 10 + 20 + 10 + 10 + 6$

$= 56$ kHz

∴ BW = 56 kHz

Chapter 4 Angle Modulation

Class Room Practice Solutions

01. Ans: (a)

Sol: $s(t) = 10\cos(20\pi t + \pi t^2)$

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

$$f_i = \frac{1}{2\pi}[20\pi + 2\pi t]$$

$$\frac{df_i}{dt} = \frac{1}{2\pi}\times 2\pi \times 1 = 1\text{Hz/sec}$$

02. Ans: (d)

03. Ans: (a)

Sol: In an FM signal, adjacent spectral components will get separated by $f_m = 5$ kHz

Since BW = $2(\Delta f + f_m)$ = 1MHz

$= 1000 \times 10^3$

$\Delta f + f_m = 500$ kHz, $\Delta f = 495$ kHz

The n^{th} order non-linearity makes the carrier frequency and frequency deviation increased by n-fold, with the base-band signal frequency (f_m) left unchanged since n = 3,

$\therefore (\Delta f)_{New} = 1485$ kHz &

$(f_c)_{New} = 300$ MHz

New BW = $2(1485 + 5) \times 10^3$

= 2.98 MHz

= 3 MHz

04. Ans: (d)

Sol: $S(t) = A_c \sum_{n=-\infty}^{\infty} J_n(\beta)\cos(2\pi f_c t + \beta \sin 2\pi f_m t)$

$\Delta f = 3(2f_m) = 12$ kHz

$$\beta = \frac{\Delta f}{f_m} = 6$$

$$\therefore S(t) = \sum_{n=-\infty}^{\infty} 5.J_n(6)\cos(2\pi f_c + \beta \sin t)$$

$f_c = 1000$kHz, $f_m = 2$ kHz

$= \cos 2\pi(1008 \times 10^3)t$

$= \cos 2\pi(1000 + 4\times 2)\times 10^3 t$

i.e., n = 4

The required coefficient is $5.J_4(6)$

05. Ans: (c)

Sol: $2\pi f_m = 4\pi\ 10^3$

$\Rightarrow f_m = 2k$

$J_0(\beta) = 0$ at $\beta = 2.4$

$$\beta = \frac{k_f\ A_m}{f_m} \Rightarrow 2.4 = \frac{k_f \times 2}{2k}$$

$k_f = 2.4$ KHz /V

at $\beta = 5.5$

$$5.5 = \frac{2.4k \times 2}{f_m}$$

$\Rightarrow f_m = 872.72$

06. Ans (c)

Sol: $\beta = 6$

$J_0(6) = 0.1506$; $J_3(6) = 0.1148$

$J_1(6) = 0.2767$; $J_4(6) = 0.3576$

$J_2(6) = 0.2429$;

$$\frac{P_{f_c \pm 4f_m}}{P_T} = ? \qquad P_T = \frac{A_c^{\,2}}{2R}$$

$$P_{f_c \pm 4f_m} = \frac{A_C^2}{R}\left[\frac{J_0^2(\beta)}{2} + J_1^2(\beta) + J_2^2(\beta) + J_3^2(\beta) + J_4^2(\beta)\right]$$

$$P_{f_c \pm 4f_m} = \frac{A_C^2}{R}\left[\frac{J_0^2(\beta)}{2} + J_1^2(\beta) + J_2^2(\beta) + J_4^2(\beta)\right]$$

$$\frac{P_{f_c \pm 4f_m}}{P_T} = \frac{0.2879}{1/2} = 0.5759 = 57.6\ \%$$

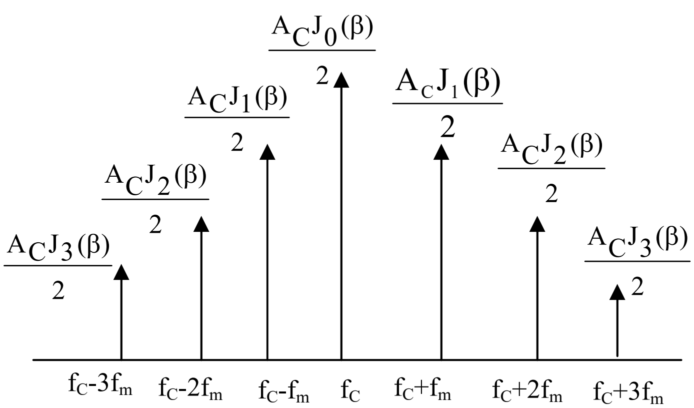
07. Ans: (c)

Sol: $m(t) = 10\cos 20\pi t$

$f_m = 10$ Hz

inserting correct signal and frequency

$$\beta = \frac{k_f A_m}{f_m} = \frac{5\times 10}{10} = 5$$



From f_c to $f_c + 4f_m$ pass through ideal BPF

Powers in these frequency components

$$P = \frac{A_C^2}{2R}J_0^2(\beta) + 2\frac{A_C^2}{2R}J_1^2(\beta) + 2\frac{A_C^2}{2R}J_2^2(\beta)$$

$$+ 2\frac{A_C^2}{2R}J_3^2\beta + 2\frac{A_C^2}{1R}J_4^2(\beta)$$

$$= \frac{A_C^2}{2R}\left[\begin{array}{l}(-0.178)^2 + 2(-0.328)^2 + 2(0.049)^2 \\ + 2(0.365)^2 + 2(0.391)^2\end{array}\right]$$

= 41.17 Watts

08. Ans: (d)

Sol: $P_t = \frac{A_C^2}{2R}$ $(R = 1\Omega)$

$$= \frac{100}{2} = 50\text{ W}$$

$$\%\ \text{Power} = \frac{\text{Power in components}}{\text{total power}} \times 100$$

$$= \frac{41.17}{50} \times 100$$

$= 82.35\%$

09. Ans: (d)

10. Ans: (c)

Sol: Given $f_c = 1$MHz

$f_{max} = f_c + k_f A_m$

$k_p = 2\pi k_f$

$$k_f = \frac{k_p}{2\pi} = \frac{\pi}{2\pi}$$

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

$$= \left(10^6 + \frac{1}{2}\times 10^5\right) = \left(10^6 + 0.5\times 10^5\right)$$

$$= \left(10^6 + 5\times 10^4\right)$$

$$= \left(10^3 + 50\right)10^3$$

$= (10^3 + 50)$ k

= 1050 kHz.

$f_{min} = f_c - k_f A_m$

$$= \left(10^6 - \frac{1}{2}\times 10^5\right)$$

$$= \left(10^6 - 0.5\times 10^5\right)$$

$$= \left(10^6 - 5\times 10^4\right)$$

$= (10^3 - 50)10^3$

$= (10^3 - 50)$ k

$= 950$ kHz

11. Ans: (d)

Sol: $\beta = \dfrac{\Delta f}{f_m}$

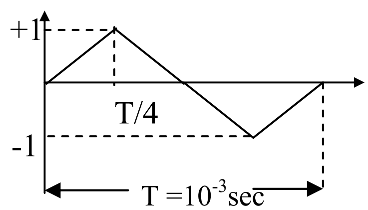
$\Delta\phi = \dfrac{\Delta f}{f_m}$

$\Delta f = \Delta\phi\, f_m$

$= k_p A_m f_m$

12. Ans: (c)

Sol: Given



$f_c = 100 \times 10^3$ Hz

$k_f = 10\times10^3$Hz

$m(t)|_{max} = +1$, $m(t)|_{min} = -1$

$f_i = f_c \pm \Delta f$

$= f_c \pm k_f A_m$

$= 100\times10^3 \pm 10\times10^3\,(m(t))$

$= 110$ kHz & 90 kHz

13. Ans: (c)

Sol: $S(t) = A_c \cos(\underbrace{2\pi f_c t + k_p m(t)}_{\theta_i(t)})$

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

$= \dfrac{1}{2\pi}\dfrac{d}{dt}(2\pi f_c t + k_p m(t))$

$= f_c + \dfrac{1}{2\pi}k_p \dfrac{d}{dt}m(t)$

$f_{max} = f_c + \dfrac{k_p}{2\pi}\dfrac{1}{\left(\frac{10^{-3}}{4}\right)} = f_c + \dfrac{k_p}{2\pi}\times 4\times 10^3$

$= 100\text{ kHz} + \dfrac{\pi}{2\pi}\times 4\times 10^3$

$= 102$ kHz

$f_{min} = f_c - k_p\dfrac{1}{\left(\frac{10^{-3}}{4}\right)}$

$= f_c - 2$ kHz

$f_{min} = 98$kHz

14. Ans: (c)

Sol: Given,

$S(t) = A_c \cos(\theta_i(t))$

$= A_c \cos(\omega_c t + \phi(t))$

$m(t) = \cos(\omega_m t)$

$f_i(t) = f_c + 2\pi k(f_m)^2 \cos\omega_m t$

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

$\theta_i(t) = \int 2\pi\, f_i(t)dt$

$\theta_i(t) = \int 2\pi[f_c + 2\pi k(f_m)^2\cos\omega_m t]dt$

$\theta_i(t) = 2\pi f_c t + (2\pi f_m)^2\, k\, \dfrac{\cos\omega_m t}{\omega_m t}$

$\theta_i(t) = \omega_c t + \omega_m k \sin\omega_m t$

15. Ans: (b)

Sol: $\Delta f_{max} = K_f\,|m(t)|_{max}$

$= \dfrac{100}{2\pi}\times[10]$

$\Delta f_{max} = \left(\dfrac{500}{\pi}\right)$Hz

16. Ans: (b)

Sol: Given that

$s(t) = \cos[\omega_c t + 2\pi m(t)]$volts

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

$$= \frac{1}{2\pi}\frac{d}{dt}\left[2\pi f_c t + 2\pi m(t)\right]$$

$$f_i = f_c + \frac{d}{dt}\left[m(t)\right]$$

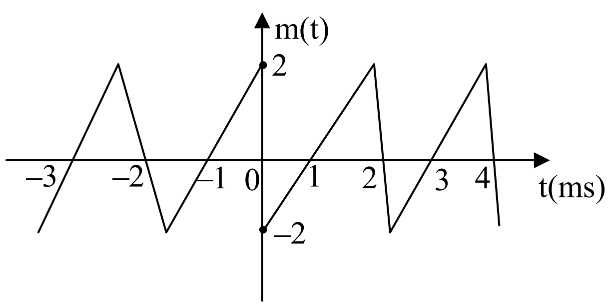
we know that $f_i = f_c + k_f m(t)$

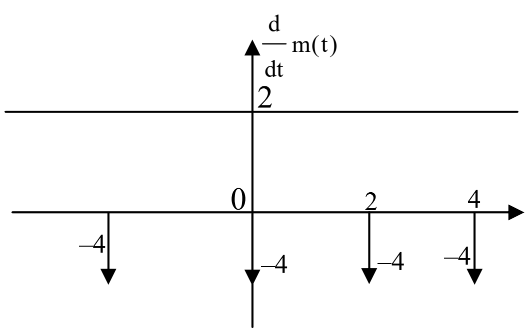
Here $k_f m(t) = \frac{d}{dt}\left[m(t)\right]$

$$\Delta f = \max\{k_f m(t)\}$$

$$\Delta f = \max\left[\frac{d}{dt}m(t)\right]$$

$$\Delta f = 2\text{kHz}$$





17. Ans: (a)

Sol: $\beta_p = k_p \max[|m(t)|] = 1.5 \times 2 = 3$

$$\beta_f = \frac{k_f \max[|m(t)|]}{f_m}$$

$$= \frac{3000\times 2}{1000}$$

$$= 6$$

18. Ans: (a)

Sol: Using Carson's rule we obtain

$BW_{PM} = 2(\beta_p + 1)f_m = 8 \times 1000 = 8000$Hz

$BW_{FM} = 2(\beta_f + 1)f_m = 14 \times 1000 = 14000$Hz

19. Ans: 70 kHz

Sol: $s(t) = A_c\cos\left[2\pi f_c t + k_p m(t)\right]$

$$f_i = f_c + \frac{k_p}{2\pi}\frac{d}{dt}x(t)$$

$$= 20k + \frac{5}{2\pi}\times 5\frac{d}{dt}\left(\sin 4\pi 10^3 t - 10\pi\cos 2\pi 10^3 t\right)$$

$$= 20k + \frac{25}{2\pi}\times\left[\begin{array}{l}\cos(4\pi 10^3 t - 10\pi\cos 2\pi 10^3 t)\\ \left(4\pi 10^3 + 10\pi\sin 2\pi 10^3 t\times 2\pi 10^3\right)\end{array}\right]$$

$$f_{i(t=0.5ms)} = 20k + \frac{25}{2\pi}\times\cos(4\pi + 10\pi)\times 4\pi\times 10^3$$

$$= 20k + \frac{25}{2\pi}\times 4\pi\times 10^3$$

$$= 20k + 50k$$

$$f_{i(t=0.5ms)} = 70\text{kHz}$$

Chapter 5 Radio Receivers

Class Room Practice Solutions

01. Ans: (d)

02. Ans: (b)

03. Ans: (d)

Sol: Given f_s = 4 to 10 MHz

IF = 1.8 MHz

f_{si} = ?

$f_{si} = f_s + 2\times IF$

= 7.6 MHz to 13.6 MHz

04. Ans: (a)

Sol: Image frequency $f_{si} = f_s + 2\times IF$

$= 700\times10^3 + 2(450\times10^3)$

= 1600 kHz

Local oscillator frequency, $f_l = f_s + IF$

$(f_l)_{max} = (f_s)_{max} + IF = 1650 + 450$

= 2100 kHz

$(f_l)_{min} = (f_s)_{min} + IF = 550 + 450$

= 1000 kHz

$$R = \frac{C_{max}}{C_{min}} = \left(\frac{f_{l\,max}}{f_{l\,min}}\right)^2 = \left(\frac{2100}{1000}\right)^2 = 4.41$$

05. Ans: (a)

Sol: f_s(range) = 88 - 108MHz

Given condition $f_{IF} < f_{LO}$, f_{si}>108 MHz

$f_{si} = f_s + 2\times IF$

f_{si} > 108 MHz

$f_s + 2IF > 108$ MHz

88MHz + 2×IF > 108 MHz

IF > 10MHz

Among the given options IF = 10.7 MHz

06. Ans: (a)

Sol: Range of variation in local oscillator frequency is

$f_{Lmin} = f_{smin} + IF$

= 88 + 10.7

f_{Lmin} = 98.7 MHz

$f_{Lmax} = f_{smax} + IF$

=108 +10.7

f_{Lmax} = 118.7 MHz

07. Ans: 5

Sol: f_s = 58 MHz– 68 MHz

When f_s = 58 MHz

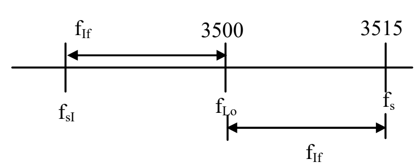
$f_{si} = f_s + 21F > 68$ MHz

21F > 10 MHz

1F ≥ 5 MHz

08. Ans: 3485 MHz

Sol:



f_{If} = 15 MHz

f_{Lo} = 3500 MHz

$f_s - f_{Lo} = f_{If}$

$f_s = f_{Lo} + f_{If}$ = 3515 MHz

f_{si} = image frequency = $f_s - 2\,f_{If}$

= 3515 − 2×15

= 3485 MHz

Chapter **6**

Baseband Data Transmission

Class Room Practice Solutions

01. Ans : (d)

Sol: $\Delta = \frac{V_{max} - V_{min}}{2^n}$

$\Delta \,\alpha\, \frac{1}{2^n}$; $\frac{\Delta_1}{\Delta_2} = \frac{2^{n_2}}{2^{n_1}}$

$\frac{0.1}{\Delta_2} = \frac{2^{n+3}}{2^n}$

$\Delta_2 = 0.1 \times \frac{1}{8}$

$= 0.0125$

02. Ans: (3)

Sol: $(BW)_{PCM} = \frac{n f_s}{2}$

Where 'n' is the number of bits to encode the signal and L = 2^n, where 'L' is the number of quantization levels.

$L_1 = 4 \Rightarrow n_1 = 2$

$L_2 = 64 \Rightarrow n_2 = 6$

$\frac{(BW)_2}{(BW)_1} = \frac{n_2}{n_1} = \frac{6}{2} = 3$

$(BW)_2 = 3\,(BW)_1$

03. Ans: (c)

Sol: Given,

Two signals are sampled with f_s = 44100s/sec and each sample contains '16' bits

Due to additional bits there is a 100% overhead.

Out put bit rate =?

$R_b = n^{|} f_s^{|}$

$f_s^{|} = 2f_{s|} = 2\,[44100]$

($\because$ two signals sampled simultaneously)

$n^{|} = 2n$

($\because$ due to overhead by additional bits)

$R_b = 4\,(nf_s) = 2.822$Mbps

04. Ans (c)

Sol: Number of bits recorded over an hour

$= R_b \times 3600 = 10.16$ G.bits

05. Ans: (c)

Sol: $p(t) = \frac{\sin(4\pi W t)}{4\pi W t\,(1 - 16 W^2 t^2)}$

At $t = \frac{1}{4W}$; $P\left(\frac{1}{4W}\right) = \frac{0}{0}$

Use L-Hospital Rule

$$\underset{t\to\frac{1}{4W}}{Lt}\; p(t) = \underset{t\to\frac{1}{4W}}{Lt} \frac{4\pi W \cos(4\pi W t)}{4\pi W - 64\pi W^3 (3t^2)}$$

$$= \frac{4\pi W(-1)}{4\pi W - 64\pi W^3\, 3\left(\frac{1}{16 W^2}\right)}$$

$$= \frac{-4\pi W}{-8\pi W} = 0.5$$

06. Ans: 35

Sol: Given bit rate R_b = 56 kbps, Roll of factor $\alpha = 0.25$

BW required for base band binary PAM system

$$BW = \frac{R_b}{2}[1+\alpha] = \frac{56}{2}[1+0.25]\text{kHz} = 35\text{kHz}$$

07. Ans: 16

Sol: $R_b = nf_s$ = 8bit/sample × 8kHz = 64 kbps

$$(B_T)_{min} = \frac{R_b}{2\log_2 M}$$

$$= \frac{R_b}{2\log_2 4} = \frac{R_b}{2\times 2}$$

$$= \frac{R_b}{4} = \frac{64}{4} = 16\,\text{kHz}$$

08. Ans: (b)

Sol: Given $f_s = 1/T_s$ = 2k symbols/sec

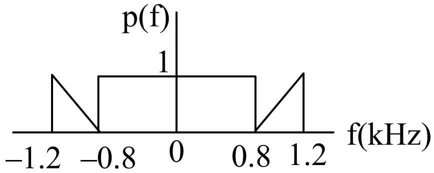
If $P(f) \overset{F.T}{\leftrightarrow} p(t)$,

Condition for zero ISI is given by

$$\frac{1}{T_s}\sum_{n=-\infty}^{\infty} P(f - n/T_s) = p(0)$$

$$\Rightarrow \sum_{n=-\infty}^{\infty} P(f - n/T_s) = p(0)T_s$$

p(0) = area under P(f)

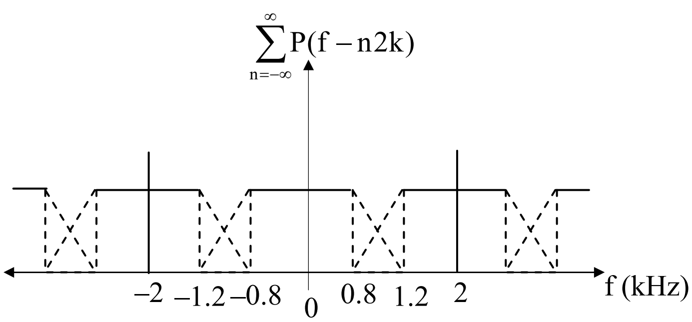


$$\text{Area} = 2\times\frac{1}{2}(1)(0.4)k + 2\times 0.8k = 2k$$

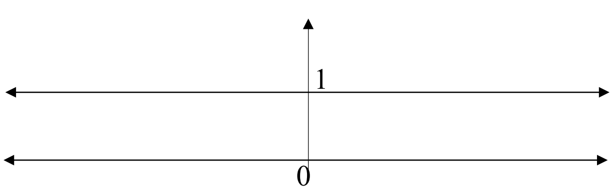
$$p(0)\,T_s = 2k \times \frac{1}{2k} = 1$$

$$\Rightarrow \sum_{n=-\infty}^{\infty} P(f - n/T_s) = 1$$

The above condition is satisfied by only option (b)



$\Downarrow$



$$\therefore \sum_{n=-\infty}^{\infty} P(f - n2k) = 1$$

Option (a) is correct if pulse duration is from –1 to + 1

Option (c) is correct if the transition is from 0.8 to 1.2, –0.8 to –1.2

Option (d) is correct if the triangular duration is from –2 to +2

09. Ans: 200

Sol: m(t) = sin 100πt + cos 100πt

$= \sqrt{2}\cos[100\pi t + \phi]$

$$\Delta = 0.75 = \frac{V_{max} - V_{min}}{L} = \frac{\sqrt{2} - (-\sqrt{2})}{L} = \frac{2\sqrt{2}}{L}$$

$$L = \frac{2\sqrt{2}}{0.75} \approx 4 = 2^n$$

So n = 2

f = 50 Hz so Nyquist rate = 100

so the bit rate = 100 × 2 = 200 bps

10. Ans: (b)

Sol: Given

$f_{m_1} = 3.6\text{kHz} \Rightarrow f_{s_1} = 7.2\text{kHz}$

$f_{m_2} = f_{m_3} = 1.2\text{kHz} \Rightarrow f_{s_2} = f_{s_3} = 2.4\text{kHz}$

$f_s = f_{s_1} + f_{s_2} + f_3$

= 12kHz

No. of Levels used = 1024

⇒ n = 10bits

∴ Bit rate = nf_s

=10 × 12 kHz

=120 kbps

11. Ans: (a)

Sol: $(f_s)_{min} = (f_{s_1})_{min} + (f_{s_2})_{min} + (f_{s_3})_{min} + (f_{s_4})_{min}$

= 200 + 200 + 400 + 800

= 1600 Hz

12. Ans: (a)

Sol: Peak amplitude → A_m

Peak to peak amplitude A_m

$$\frac{-\Delta}{2} \le Q_e \le \frac{\Delta}{2}$$

PCM maximum tolerable $\frac{\Delta}{2} = 0.2\%\ A_m$

$$\Delta = \frac{\text{Peak to peak}}{L} \Rightarrow \frac{2A/m}{2L} = \frac{0.2}{100} A_m$$

$$(\because \Delta = \frac{2A_m}{L})$$

$\Rightarrow L = 500$

$2^n = 500$

$n = 9$

$R_b = n(f_S)_{TDM} + 9$

$f_S = R_N + 20\%R_N = R_N + 0.2R_N$

$f_S = 1.2R_N = 1.2 \times 2 \times \omega$

$f_S = 2.4$ K samples/sec

$(f_S)_{TDM} = 5(f_S)$

$= 5 \times 2.4$ K

$= 12$ K sample/sec

$R_b = (nf_S) + 0.5\%(nf_S)$

$= (9 \times 12k) + \frac{0.5}{100}(9 \times 12k)$

$= 108540$ bps

13. Ans: (b)

Sol: Number of patients = 10

ECG signal B.W = 100Hz

$(Q_e)_{max} \le (0.25)\ \%V_{max}$

$$\frac{2V_{max}}{2 \times 2^n} \le \frac{0.25}{100} V_{max}$$

$2^n \ge 400$

$n \ge 8.64$

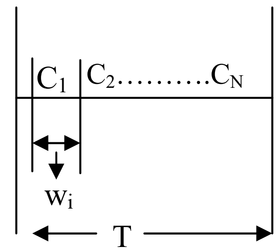
$n = 9$

Bit rate of transmitted data = $10 \times 9 \times 200$

$= 18$kbps

14. Ans: (c)

Sol:



Minimum B.W of TDM is $\sum_{i=1}^{N} w_i$

15. Ans: (b)

Sol: To avoid slope over loading, rate of rise of the o/p of the Integrator and rate of rise of the Base band signal should be the same.

$\therefore \Delta f_s$ = slope of base band signal

$\Delta \times 32 \times 10^3 = 125$

$\Delta = 2^{-8}$ Volts.

16. Ans: (b)

Sol: $x(t) = E_m \sin 2\pi f_m(t)$

$\frac{\Delta}{T_S} < \left|\frac{dm(t)}{dt}\right| \rightarrow$ slope overload distortion takes place

$\Delta f_S < E_m 2\pi f_m$

$\Rightarrow \frac{\Delta f_S}{2\pi} < E_m f_m \qquad (\because \Delta = 0.628)$

$\Rightarrow \frac{0.628 \times 40K}{2\pi} < E_m f_m$

$f_S = 40$ kHz $\Rightarrow 4$ kHz $< E_m f_m$

Check for options

(a) $E_m \times f_m = 0.3 \times 8$ K $= 2.4$ kHz

$(4K \not< 2.4\ K)$

(b) $E_m \times f_m = 1.5 \times 4K = 6$ kHz

$(4K < 6\ K)$ correct

(c) $E_m \times f_m = 1.5 \times 2\text{ K} = 3\text{ kHz}$

$(4K \nless 3K)$

(d) $E_m \times f_m = 30 \times 1\text{ K} = 3\text{ kHz}$

$(4K \nless 3K)$

17. Ans: (a)

Sol: Given

$m(t) = 6\sin(2\pi\times10^3 t) + 4\sin(4\pi\times10^3 t)$

$\Delta = 0.314\text{ V}$

Maximum slope of m(t) = $\frac{d}{dt}(m(t))/t = \frac{\pi}{2}$

$= 2\pi\times10^3(6) + 4\pi\times10^3[4] = 28\pi\times10^3$

18. Ans: (c)

Sol: Pulse rate which avoid distortion

$$\Delta f_s = \frac{d}{dt}m(t)$$

$$f_s = \frac{28\pi\times10^5}{0.314}$$

$f_s = 280\times10^3$ pulses/sec

Chapter 7 Bandpass Data Transmission

Class Room Practice Solutions

01. Ans: (c)

Sol: $(BW)_{BPSK} = 2f_b = 20$ kHz

$(BW)_{QPSK} = f_b = 10$ kHz

02. Ans: (b)

Sol: $f_H = 25$ kHz ; $f_L = 10$ kHz

∴ Center frequency

$$= \left(\frac{25+10}{2}\right) \text{kHz} = 17.5 \text{ kHz}$$

∴ Frequency offset,

$\Omega = 2\pi\,(25 - 17.5) \times 10^3$

$= 2\pi\,(7.5) \times 10^3$

$= 15 \times 10^3\pi$ rad/sec.

The two possible FSK signals are orthogonal, if $2\Omega T = n\pi$

$\Rightarrow 2(15\pi) \times 10^3 \times T = n\pi$

$\Rightarrow 30 \times 10^3 \times T = n$ (integer)

This is satisfied for, T = 200μsec.

03. Ans: (a)

Sol: $r_b = 8$ kbps

Coherent detection

$\Delta f = \frac{nr_b}{2}$

Best possible n = 1

$\Delta f = \frac{8K}{2} = 4K$

To verify the options Δf = 4k

i.e. $f_{C2} - f_{C1} = 4K$

(a) 20 K – 16 K = 4 K

(b) 32 K – 20 K = 12 K

(c) 40 K – 20 K = 20 K

(d) 40 K – 32 K = 8 K

04. Ans: (a) & (c)

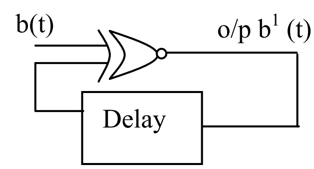
05. Ans: (c)

Sol: In QPSK baud rate $= \frac{\text{bit rate}}{2} = \frac{34}{2}$

= 17 Mbps

06. Ans: (d)

Sol:



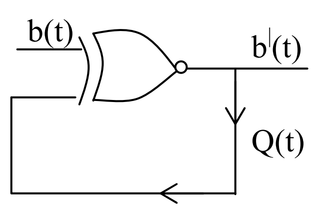
b(t)	0	1	0	0	1
$b^1(t)_{\textbf{(Ref.bit)}}$	0	0	1	0	0
Phase	π	π	0	π	π

07. Ans: (b)

Sol: Given

Bit stream 110 111001

Reference bit = 1



$b^|(t) = b(t) \odot Q(t)$

```
  1 1 0 1 1 1 0 0 1
1
  1 1 0 0 0 0 1 0 0
  ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓
  0 0 π π π π 0 π π
```

08. Ans: (d)

Sol: $r_b = 1.544 \times 10^6$

$\alpha = 0.2$

$$BW = \frac{r_b}{\log_2^M}(1+\alpha)$$

$$= \frac{1.544\times10^6}{2}(1+0.2) \quad (\because M = 4)$$

$BW = 926.4 \times 10^3$ Hz

09. Ans: 0.25

Sol: BW = 1500 Hz

BW required for M-ary PSK is

$$\frac{R_b[1+\alpha]}{\log_2 16} = 1500\text{Hz}$$

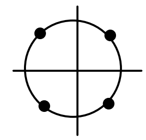
$\Rightarrow R_b [1 + \alpha] = 1500 \times 4 = 6000$

$$\Rightarrow (1+\alpha) = \frac{6000}{4800}$$

Roll off factor $\Rightarrow \alpha = \frac{6000}{4800} - 1 = 0.25$

10. Ans: (b)

Sol:



Minimum shift keying

11. Ans: (b)

12. Ans: (d)

Sol: $BW = \frac{r_b}{\log_2 M}(1+\alpha)$

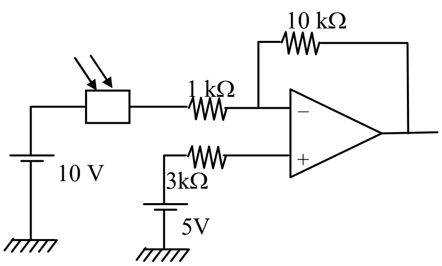
$$36\times10^6 = \frac{r_b}{2}(1+0.2)(\because M = 4, \text{QPSK})$$

$r_b = 60\times10^6$ bps

Chapter 1 Optical Sources and Detectors

Class Room Practice Solutions

01.
Sol:



1^{st} case:

$R_p \rightarrow 1\ k\Omega$, no 10 V source

2^{nd} case:

$R_p \rightarrow 5\ k\Omega \rightarrow 10$ V source is present

So, $V = V_{01(Only 10V)} + V_{02(Only 5V)}$

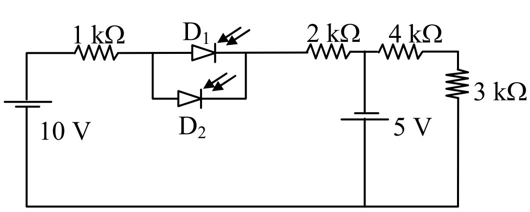
$$V = \frac{-10\,k\Omega}{1k\Omega + R_p}$$

$$= \left(\frac{-10k\Omega}{1k\Omega + 5k\Omega}\right)\times 10 + \left(1 + \frac{10k\Omega}{1k\Omega + 1k\Omega}\right)\times 5$$

$$V = \left(\frac{-10k\Omega}{6k\Omega}\times 10\right) + \left(1 + \frac{10k\Omega}{2k\Omega}\right)\times 5$$

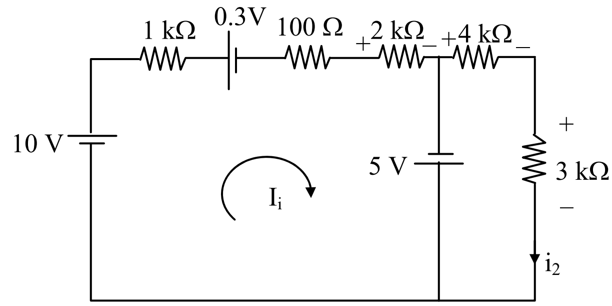
$V = 13.33$ V

02.
Sol:



D_1, D_2 are in forward bias

D_2–ON, D_1 –OFF



$V_{2k} = ?$

$V_{3k\,\Omega} = ?$

$$i_2 = \frac{-5V}{4k\Omega + 3k\Omega} = \frac{-5V}{7k\Omega} = -0.714\ mA$$

$V_{3k\,\Omega} = i_2 \times 3\ k\Omega$

$= (-0.714) \times 3 \times 10^3$

$= -2.14$ V

From circuit

$I_i = 1.41$ mA

So

$V_{2k} = 1.41\ mA \times 2\ k\Omega = 2.8$ V

03. Ans: (c)

Sol: Given data.

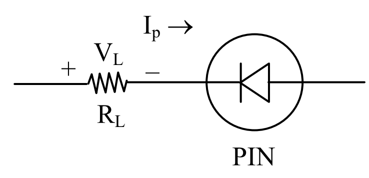
$C_j = 6$ pF

$A = 10\ mm^2$

$R = 0.5$ A/W

$I = 1 mW/cm^2$

$R_L = 100\ k\Omega$



$V_L = ?$

We know

$V_L = I_P \times R_L$

$$R = \frac{I_p}{P_0}$$

$P_0 = A \times I$

$$I_p = \frac{0.5A}{W} \times A \times I$$

$$I_p = \frac{0.5A}{W} \times 10mm^2 \times \frac{1mW}{10mm^2}$$

$$I_p = \left(0.5 \times \frac{10}{100} \times 1m\right) Amp$$

$$I_p = 5 \times 10^{-5} \text{ amp}$$

$$V_L = I_p \times R_L = 5 \times 10^{-5} \times 100 \text{ k}\Omega$$

$$\therefore V_L = 5 \text{ volts}$$

04. Ans: (c)

Sol: Given:

$\eta = 0.65$

$\lambda = 900$ nm

$P_0 = 0.5$ μw

$I_m = 10$ μA

M = ?

$$M = \frac{I_m}{I_p} = \frac{10\mu A}{I_p}$$

We know

$$\eta = \frac{EI_p}{P_0 q}$$

$$0.65 = \frac{hcI_p}{\lambda P_0 q}$$

$$\Rightarrow 0.65 = \left(\frac{6.6 \times 10^{-34} \times 3 \times 10^8}{900n \times 0.5 \times 10^{-6} \times 1.6 \times 10^{-19}}\right) \times I_p$$

$$\Rightarrow \quad I_p = 2.36 \times 10^{-7}$$

$$M = \frac{10\mu A}{2.36 \times 10^{-7} A}$$

$$= 42.4 \approx 43$$

05. Ans: -1V

Sol: Output is independent V_r

06. Ans: 2

Sol: Given

Area = 10 mm^2

Sensitivity = 0.5 A/W

Intensity = 4 W/m^2

Photodiode current

I_p = Area × sensitivity × Intensity

$I_P = 10\ mm^2 \times 0.5\ A/W \times 4W/m^2$

$I_p = 20$ μA

I to V converter sensitivity is 100 mV/μA

$$\text{So, } V_o = \frac{100mV}{\mu A} \times 20\mu A$$

$$= 2 \text{ Volt}$$

07. Ans: 75.18

Sol: $$\frac{I}{P} = \frac{\eta e \lambda}{hc}$$

$$I = \frac{\eta e \lambda}{hc} \times P$$

$$= \frac{0.75 \times 1.6 \times 10^{-19} \times 830 \times 10^{-9} \times 100 \times 10^{-6}}{6.624 \times 10^{-34} \times 2 \times 10^8}$$

$$I = 75.18\mu A$$

Chapter **2**

LED's & LASERs

Class Room Practice Solutions

01. Ans: (b)

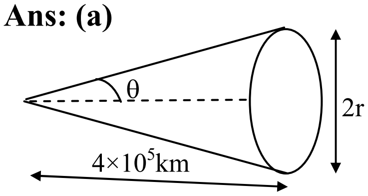
Sol: $2i = 115^0.34' = 115.566^0$,

$i = 57.783^0$, $\quad u = \tan i = \tan 57.783^0$

$= 1.587$

02. Ans: (a)

Sol:



$\theta = 1$ m rad

$$\tan\theta = \frac{r}{4\times10^5\times1000} = 1 \text{ mrad}$$

$(\tan\theta\approx\theta)$

$r = 4\times10^5$ meters

$= 400$ km

Diameter $= 2\times r$

$= 2\times400$ km

$= 800$ km

03. Ans: (b)

Sol: Given:

L = 500 mm

Bandwidth = 1500 MHz

$\Delta f = ?$

Number of longitudinal oscillating modes

$$= \frac{BW}{\Delta f}$$

We know

$$\Delta f = \frac{C}{2L}$$

Number of longitudinal oscillating modes

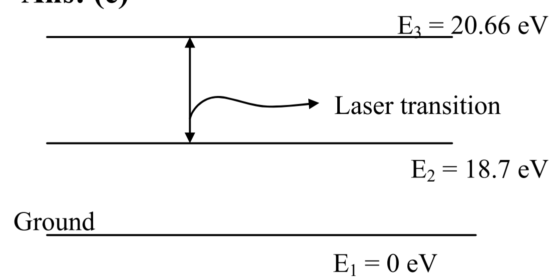
$$= \frac{1500\,\text{MHz}}{\left(\dfrac{3\times10^8}{2\times500\times10^{-3}}\right)}$$

$$= \frac{1500\times10^6}{3\times10^8}\times1000\times10^{-3}$$

$= 5$

04. Ans: (c)

Sol:



05. Ans: (c)

Sol: $E_3 - E_2 = \dfrac{hc}{\lambda}$

$$\lambda = \frac{hc}{E_3 - E_2}$$

$$= \frac{6.625\times10^{-34}\times3\times10^8}{(20.66-18.7)\times1.6\times10^{-19}\,J}$$

$= 633.8$ nm

06. Ans: (d)

Sol: Given

$\lambda = 6328$ A

Bandwidth = 1 MHz

$C_l = ?$

We know

$$C = \frac{C_\ell}{C_t}$$

$$C_l = 3\times10^8\times\frac{1}{1\text{MHz}} \quad (\because C_t = \frac{1}{f})$$

$C_l = 300$ m

07. Ans: 40

Sol: for photo diode D_1

Intensity = $50 W/m^2$

Area $= 10\times 10^{-3}\times(5\times10^{-3}+100\times10^{-6})m^2$

$= 2.55\times10^{-3}m^2$

Total current of diode D_1

$I_{D1} = 2.55\times10^{-3}\times 0.4A = 1.02\times10^{-3}A$

For photo diode D_2

Intensity = $50W/m^2$

Area = $10\times 10^{-3} \times (5\times10^{-3}-100\times10^{-6})m^2$

$= 2.45 \times 10^{-3}m^2$

Total current of diode D_2

$I_{D2} = 2.45\times10^{-3}\times 0.4A = 9.8\times10^{-4}A$

Difference between photo currents

$I_{D1}-I_{D2} = 1.02\times10^{-3}A - 9.8\times10^{-4}A$

$= 40\mu A$

08. Ans: 2

Sol: $E_g = \frac{hC}{\lambda}$

$$E_g = \frac{4.13567\times10^{-15}\times3\times10^{8}}{620\times10^{-9}} = 2eV$$

Chapter **3**

Interferometers

Class Room Practice Solutions

01.

Sol: Given data:

$t = 5\ \mu m$

$n = 5$

$\lambda = 589$ nm

$\mu_g = ?$

We know

$t(\mu_g - 1) = n\lambda$

$\Rightarrow 5\times10^{-6}(\mu_g - 1) = 5\times589\times10^{-9}$

$$\Rightarrow (\mu_g - 1) = \frac{5\times589\times10^{-9}}{5\times10^{-6}}$$

$\Rightarrow (\mu_g - 1) = 0.589$

$\Rightarrow \mu_g = 1.589$

02.

Sol: Given data:

$\lambda = 515$ nm

Refractive index (μ) = 1.6

$\theta_R = 45^o$

$t = ?$

we know

$t(\mu - 1) = n\lambda$

$$t = \frac{n\lambda}{(\mu - 1)}$$

$$\Rightarrow t = \frac{515\times10^{-9}}{1.6 - 1} = 8.58\times10^{-7}$$

$\Rightarrow t = 0.85\ \mu m$

03.

Sol: Given data

$t = 1.5\ \mu m$

$\lambda = 0.5\ \mu m$

$n = ?$

We know

$$t = \frac{n\lambda}{2}$$

$$\Rightarrow 1.5\times10^{-6} = \frac{n\times0.5\times10^{-6}}{2}$$

$$\Rightarrow \frac{1.5\times10^{-6}\times2}{0.5\times10^{-6}} = n$$

$\Rightarrow n = 6$

04.

Sol: Given data:

$n = 100$

$\lambda = 6328A^o$

$t = 20$ cm

$\mu = ?$

We know

$$2t(\mu - 1) = n\lambda$$

$\Rightarrow 2\times20\times10^{-2}(\mu - 1) = 100\times6328\times10^{-10}$

$\mu = 1.0001582 \approx 1$

05.

Sol: Given data

R.I = $\mu_g = 1.53$

$\mu_{air} = 1.0$

$$R = \left(\frac{\mu_g - \mu_{air}}{\mu_g + \mu_{air}}\right)^2$$

$R = 0.044$

$R = 4.4$ % of loss

Chapter **4**

Fiber Optics

Class Room Practice Solutions

01. Ans: (d)

Sol: $NA = \sqrt{n_1^2 - n_2^2}$

$= \sqrt{(1.44)^2 - (1.4)^2}$

$= 0.34$

02. Ans: (c)

Sol: Given data

$\varepsilon_r = 2.5$

$n = ?$

n = refractive index

We know,

$n = \sqrt{\varepsilon_r \mu_r}$

ε_r = relative permittivity

μ_r = relative permeability

$n = \sqrt{2.5}$ $(\because \mu_r = 1)$

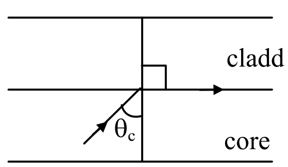
$= 1.58$

03. Ans: (d)

Sol: $n_1 = 1.6$

$n_2 = 1.422$

$\theta_c = ?$



$$\frac{\sin\theta_c}{\sin 90^o} = \frac{n_2}{n_1}$$

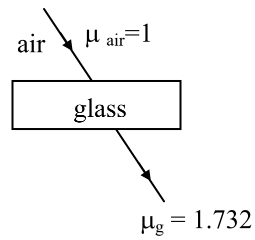
$$\theta_c = \sin^{-1}\left(\frac{1.422}{1.64}\right)$$

$= 60.12$

$\simeq 60$

04. Ans: (c)

Sol: $\mu_g = 1.732$



$$\tan\theta_B = \frac{\mu_g}{\mu_{air} = 1}$$

$$\theta_B = \tan^{-1}(1.732)$$

$$\theta_B = 60^o$$

05. Ans: (a)

Sol: Given $\mu_{glass} = 1.720$

$$R = \left(\frac{\mu_{air} - \mu_{glass}}{\mu_{air} + \mu_{glass}}\right)^2 \times 100$$

$$R = \left(\frac{1 - 1.72}{1 + 1.72}\right)^2 \times 100$$

$= 7\ \%$

06. Ans: (d)

Sol: $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

Given

$n_1 = 1.641$

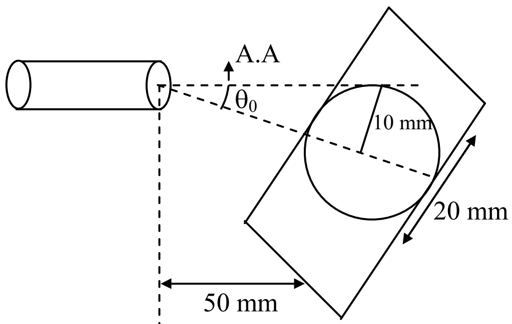
$n_2 = 1.422$

$$\theta_c = \sin^{-1}\left(\frac{1.422}{1.641}\right)$$

$= 60^o$

08. Ans: (b)

Sol: NA = ?



$$NA = \sqrt{n_1^2 - n_2^2}$$

$$NA = \mu_0 \sin\theta_0$$

$$NA = \sin\theta_0$$

$$NA = \frac{10}{\sqrt{10^2+50^2}}$$

$$= 0.196$$

$$\approx 0.2$$

09. Ans: 0.75

Sol: $\frac{n_1}{n_2} = \frac{t_1}{t_2} = 0.75 \quad (n \propto t)$