$\boxed{9.2}$

Homework 11

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12-6-06

(a) $\frac{P_4}{P_1} = 10^{-4}$ $\qquad$ $\frac{P_2+P_3}{P_1} = 10^{-1/5}$ $\qquad$ $\frac{P_2}{P_3} = 4$

$$\boxed{P_4 = 10^{-4} P_1}$$

$$\frac{5P_3}{P_1} = 10^{-1/5}$$

$$P_2 + \frac{1}{5}\left(10^{-1/5}\right)P_1 = 10^{-1/5} P_1$$

$$P_2 = \frac{4}{5}\left(10^{-1/5}\right)P_1$$

$$P_3 = \frac{1}{5}\left(10^{-1/5}\right)P_1$$

$$\boxed{P_3 = 0.126\ P_1} \qquad \boxed{P_2 = 0.505\ P_1}$$

(b) $L_{THP} = -10 \log \frac{P_2}{P_1} = -10 \log 0.505 = 2.969\ dB = \boxed{2.97\ dB}$

$L_{TAP} = -10 \log \frac{P_3}{P_1} = -10 \log 0.126 = \boxed{8.99\ dB}$

(c) $L_E = -10 \log \frac{P_2+P_3}{P_1} = \boxed{2\ dB}$

(9.8) $L = -10 \log\left(\frac{1}{5}\right) + L_E + 2L_c = -10 \log\left(\frac{1}{5}\right) + 0$

$$\boxed{L = 6.99\ dB}$$

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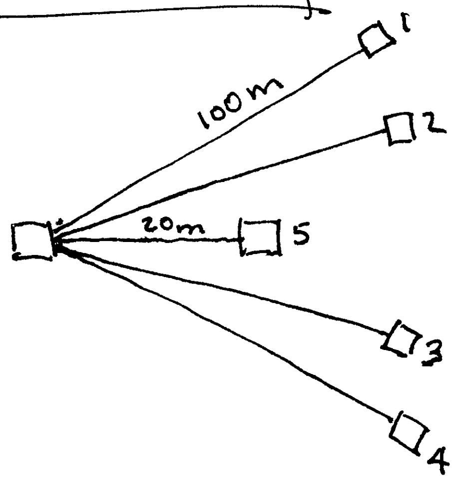
(9.9)



$L_E = 2\,dB$

$L_c' = 0.8\,dB$

$L_f = \frac{35\,dB}{km}$

$L_s' = 0.2\,dB$

Not using any splice.

Terminals 2-4:

$L_c = 3(0.8\,dB) = 2.4\,dB$

$L = -10\log\left(\frac{1}{5}\right) + 2\,dB + 2.4\,dB + 3.5\,dB = \boxed{14.89\,dB}$

Terminal 5: $L_c = 3(0.8\,dB) = 2.4\,dB$

Input to star coupler: $L_f = \frac{35\,dB}{km}(0.02\,km) = 0.7\,dB$

Then $L = -10\log\left(\frac{1}{4}\right) + L_E + L_c + L_f$

$L = 6.02\,dB + 2\,dB + 2.4\,dB + 0.7\,dB + 3.5\,dB$

$L = \boxed{14.62\,dB}$

Terminals 2-4: Input to star: $L_f = 3.5\,dB$

Then $L = 6.02\,dB + 2\,dB + 2.4\,dB + 3.5\,dB + 3.5\,dB$

$L = \boxed{17.42\,dB}$

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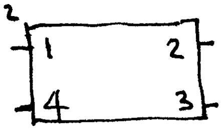
(9.23) λ_1, λ_2



$\Delta\beta_1 = 2\ \text{mm}^{-1}$

p.285 (9.12)

$\lambda_1 \rightarrow 3 \qquad \lambda_2 \rightarrow 2$

(a) Find interaction length L $\qquad L_{c_1} = \dfrac{\pi}{2\Delta\beta_1} = 0.7854\ \text{mm}$

(b) Find $\Delta\beta_2$ $\qquad$ ~~Know:~~ $\cancel{\dfrac{P_3}{P_1} = 1 = \sin^2(\Delta\beta_1 L)}$

~~Since all of λ_2 goes to Port 2~~

$\cancel{\lambda_1 : \quad \dfrac{P_2}{P_1} = 0 = \cos^2(\Delta\beta_1 L_{c_1}) \Rightarrow \Delta\beta_1 L_{c} = \dfrac{\pi}{2}}$

$\cancel{\dfrac{P_3}{P_1} = 1 = \sin^2(\Delta\beta_1 L_{c_1}) \Rightarrow \Delta\beta_1 L_{c_1} = \dfrac{\pi}{2}}$

$\cancel{L_{c_2} = \dfrac{\pi}{2\beta_2}}$

(a) $L = 3 L_{c_1} = 3\,(0.7854\ \text{mm})$

$L = \boxed{2.356\ \text{mm}}$ $\qquad$ (p.301)

(b) Find $\Delta\beta_2$. $\qquad \left.\begin{aligned} L_{c_2} &= \tfrac{1}{2} L \\ \beta_2 &= \dfrac{\pi}{2 L_{c_2}} \end{aligned}\right\} \Rightarrow \beta_2 = \dfrac{\pi}{L}$

$\beta_2 = \boxed{1.333\ \text{mm}^{-1}}$

(c) Find $L_{c_2} = \tfrac{1}{2} L = \boxed{1.178\ \text{mm}}$

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9.33 $\lambda_1 = 820$ nm $\Delta\lambda = 2$ nm Si glass, single mode
$\lambda_2 = 1300$ nm
$\lambda_3 = 1550$ nm

a) Find NRZ rate-length product.

b) Loss budget = 50 dB. Find max L.

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a From Fig 3.8 and Ex 3.1 : when $\lambda = 0.82\,\mu m$,

$$M = 110 \frac{ps}{nm \cdot km}$$

Eq. 3.14 (modified):

$$\Delta\left(\frac{\tau}{L}\right) = |M|\,\Delta\lambda = 110 \frac{ps}{nm \cdot km}(2\,nm) = 220 \frac{ps}{km}$$

$$\Rightarrow f_{3dB_{opt}} \times L = \frac{1}{2\Delta\left(\frac{\tau}{L}\right)} = \frac{1}{440}\frac{km}{ps} = \frac{10^{12}}{440}\,bps \cdot km$$

now $f_{3dB_{ele}} = 0.71\, f_{3dB_{opt}}$ and $R_{NRZ} \times L = 2 f_{3dB\,ele}$

$$\Rightarrow f_{3dB_{ele}} \times L = \frac{0.71(10^{12})}{440}\,bps \cdot km$$

$$\Rightarrow R_{NRZ} \times L = \frac{0.71(10^{12})}{220}\,bps \cdot km = \boxed{3.23\ Gbps \cdot km}$$

for $\lambda = 0.82\,\mu m$

- For $\lambda = 1.3\,\mu m$, $M = 0$

So we can skip this.

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9.33 (a) cont'd

- For $\lambda = 1.55\ \mu m$, Fig. 3.8 shows that M is much smaller in magnitude that M for $\lambda = 0.82\ \mu m$. So we can skip this.

The required NRZ rate-length product is $\geq$ $\boxed{3.23 \text{ Gbps}\cdot\text{km}}$

(b) From Table 5.5 we find that single-mode (5 μm core) glass fiber carrying 820 nm will have loss exceeding $4\ \text{dB}\cdot\text{km}^{-1}$.

So $L_{max} < \dfrac{50\ \text{dB}}{4\ \text{dB}\cdot\text{km}^{-1}} = \boxed{12.5\ \text{km}}$

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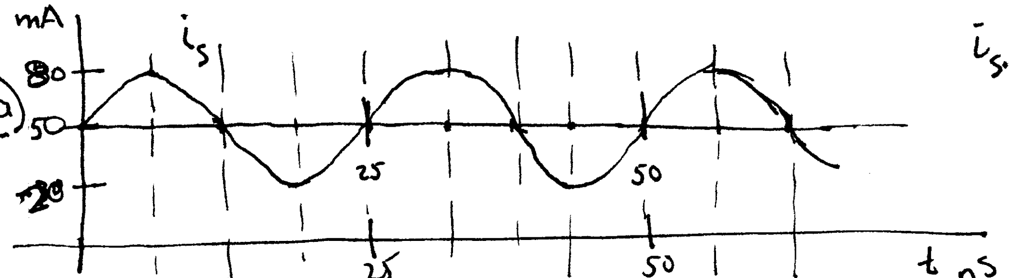
(10-1) LED $f_{3dB_{opt}} = 80\ \text{MHz}$ $\rho = 0.1\ \frac{W}{A}$ $i_{dc} = 50\ \text{mA}$

$i_s = 60\ \text{mA}_{pp}$ @ 40 MHz

(a)



(b) $m' = \dfrac{i_{sp}}{i_{dc}} = \dfrac{3}{5} = \boxed{0.6}$

(c) $P = P_{dc} + P_{sp} \sin \omega t$

$$P_{sp} = \frac{\rho\, i_{sp}}{\sqrt{1+(\omega\tau)^2}} \quad \text{and} \quad \tau = \frac{1}{2\pi f_{3dB}}$$

$$P_{sp} = \frac{0.1 \frac{mW}{mA}(30\ mA)}{\sqrt{1+\left(\frac{2\pi\cdot 40}{2\pi\cdot 80}\right)^2}} = \frac{3\ mW}{\sqrt{\frac{5}{4}}} = 2.683\ mW$$

$$\boxed{P = \left[5 + 2.68 \sin\left(80(10^6)\pi t\right)\right] mW}$$

see graph →

(d) $m = \dfrac{P_{sp}}{P_{dc}} = \dfrac{2.68}{5} = \boxed{0.537}$

$i_{scp} = i_{scp1} = i_{scp2}$ D. Bozarth

subcarrier amplitude peak

(10.14) 2 ch, FDM, AM/IM, LED $\omega_{sc1}, \omega_{sc2}, \omega_{m1}, \omega_{m2}$

(a) Find P_{opt} $m_1' = m_2' = m'$

$$P = P_{dc} + a(i_{s1} + i_{s2}) + b(i_{s1}^2 + i_{s2}^2)$$ from Eq. 10-8

modulation current
$$\begin{cases} i_{s1} = i_{sp1} \sin\omega_{m1} t = i_{sp} \sin\omega_{m1} t \\ i_{s2} = i_{sp2} \sin\omega_{m2} t = i_{sp} \sin\omega_{m2} t \end{cases}$$

modulated subcarrier current
$$\begin{cases} i_{s1} = i_{scp} (1 + m' \cos\omega_{m1} t) \cos\omega_{sc1} t \\ i_{s2} = i_{scp} (1 + \underbrace{m' \cos\omega_{m2} t}_{\text{modulating current}}) \cos\omega_{sc2} t \end{cases}$$

peak subcarrier current; subcarrier only; modulating current

$$P = P_{dc} + a\Big(i_{scp}\big[(1+m'\cos\omega_{m1}t)\cos\omega_{sc1}t + (1+m'\cos\omega_{m2}t)\cos\omega_{sc2}t\big]\Big)$$
$$+ b\, i_{scp}^2 \Big[\cos^2\omega_{sc1}t\,(1 + 2m'\cos\omega_{m1}t + (m')^2\cos^2\omega_{m1}t) + \cos^2\omega_{sc2}t\,(1 + 2m'\cos\omega_{m2}t + (m')^2\cos^2\omega_{m2}t)\Big]$$

cont'd

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(10-14) cont'd (a)

$$P = P_{dc}$$
$$+ a\, i_{scp}\Big[\cos(\omega_{sc1} t) + m' \cos(\omega_{m1} t)\cos(\omega_{sc1} t)$$
$$+ \cos(\omega_{sc2} t) + m' \cos(\omega_{m2} t)\cos(\omega_{sc2} t)\Big]$$

$$+ b\, i_{scp}^2\Big[\cos^2(\omega_{sc1} t) + 2m' \cos^2(\omega_{sc1} t)\cos(\omega_{m1} t)$$
$$+ (m')^2 \cos^2(\omega_{sc1} t)\cos^2(\omega_{m1} t)$$
$$+ \cos^2(\omega_{sc2} t) + 2m' \cos^2(\omega_{sc2} t)\cos(\omega_{m2} t)$$
$$+ (m')^2 \cos^2(\omega_{sc2} t)\cos^2(\omega_{m2} t)\Big]$$

....

$$P = P_{dc}$$
$$+ a\, i_{scp}\Big[\cos(\omega_{sc1} t) + m'\left(\tfrac{1}{2}\right)\cos((\omega_{m1} + \omega_{sc1}) t)$$
$$+ \tfrac{1}{2} m' \cos((\omega_{sc1} - \omega_{m1}) t)$$
$$+ \cos(\omega_{sc2} t) + \tfrac{1}{2} m' \cos(\omega_{sc2} + \omega_{m2}) t$$
$$+ \tfrac{1}{2} m' \cos(\omega_{sc2} - \omega_{m2}) t\Big]$$
$$+ b\, i_{scp}^2\Big[\cos^2(\omega_{sc1} t)$$
$$+ m' \cos(\omega_{sc1} t)\cos(\omega_{sc1} + \omega_{m1}) t$$
$$+ m' \cos(\omega_{sc1} t)\cos(\omega_{sc1} - \omega_{m1}) t$$
$$+ \ldots$$

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10-14 (a) cont'd

$$\cdots + \frac{1}{2}(m')^2\left(\cos(\omega_{sc1}t + \omega_{m1}t) + \cos(\omega_{sc1}t - \omega_{m1}t)\right)^2$$

$$+ \left\{ \text{same pattern using } \omega_{sc2}, \omega_{m2} \right\}$$

$$P = P_{dc} + a i_{sp}\cos\omega_{sc1}t + a i_{sp}\cos\omega_{sc2}t$$

$$+ \frac{1}{2}m' a i_{scp}\cos(\omega_{sc1} + \omega_{m1})t$$

$$+ \frac{1}{2}m' a i_{scp}\cos(\omega_{sc1} - \omega_{m1})t$$

$$+ \frac{1}{2}m' a i_{scp}\cos(\omega_{sc2} + \omega_{m2})t$$

$$+ \frac{1}{2}m' a i_{scp}\cos(\omega_{sc2} - \omega_{m2})t$$

$$+ b i_{scp}^2\cos\omega_{sc1}t + b i_{scp}^2 m'\cos\omega_{m1}t$$

$$+ b i_{scp}^2\cos\omega_{sc2}t + b i_{scp}^2 m'\cos\omega_{m2}t$$

$$+ \frac{1}{2}b i_{scp}^2(m')^2\left[\cos^2(\omega_{sc1} + \omega_{m1})t + \cos^2(\omega_{sc1} - \omega_{m1})t\right]$$

$$+ \frac{1}{2}b i_{scp}^2(m')^2\left[\cos^2(\omega_{sc2} + \omega_{m2})t + \cos^2(\omega_{sc2} - \omega_{m2})t\right]$$

$$+ \frac{1}{4}b i_{scp}^2(m')^2\left[\cos 2\omega_{sc1}t + \cos 2\omega_{m1}t\right]$$

$$+ \frac{1}{4}b i_{scp}^2(m')^2\left[\cos 2\omega_{sc2}t + \cos 2\omega_{m1}t\right]$$

$$+ \frac{1}{2}b i_{scp}^2 m'\left[\cos(2\omega_{sc1} + \omega_{m1})t + \cos(2\omega_{sc1} - \omega_{m1})t\right]$$

$$+ \frac{1}{2}b i_{scp}^2 m'\left[\cos(2\omega_{sc2} + \omega_{m2})t + \cos(2\omega_{sc2} - \omega_{m2})t\right]$$

10.14 (a) cont'd

$$P = P_{dc} + (a\, i_{scp} + b\, i_{scp}^2)(\cos\omega_{sc1}t + \cos\omega_{sc2}t) + b\, i_{scp}^2 m'(\cos\omega_{m1}t + \cos\omega_{m2}t)$$

$$+ \tfrac{1}{2} a\, i_{scp} m' \left[\cos(\omega_{sc1}+\omega_{m1})t + \cos(\omega_{sc1}-\omega_{m1})t + \cos(\omega_{sc2}+\omega_{m2})t + \cos(\omega_{sc2}-\omega_{m2})t\right]$$

$$+ \tfrac{1}{2} b\, i_{scp}^2 (m')^2 \left[\cos^2(\omega_{sc1}+\omega_{m1})t + \cos^2(\omega_{sc1}-\omega_{m1})t + \cos^2(\omega_{sc2}+\omega_{m2})t + \cos^2(\omega_{sc2}-\omega_{m2})t\right]$$

$$+ \tfrac{1}{4} b\, i_{scp}^2 (m')^2 \left[\cos 2\omega_{sc1}t + \cos 2\omega_{m1}t + \cos 2\omega_{sc2}t + \cos 2\omega_{m2}t\right]$$

$$+ \tfrac{1}{2} b\, i_{scp}^2 m' \left[\cos(2\omega_{sc1}+\omega_{m1})t + \cos(2\omega_{sc1}-\omega_{m1})t + \cos(2\omega_{sc2}+\omega_{m2})t + \cos(2\omega_{sc2}-\omega_{m2})t\right]$$

16 freqs: ω_{sc1}, ω_{sc2}, ω_{m1}, ω_{m2}

$\omega_{sc1}+\omega_{m1}$, $\omega_{sc1}-\omega_{m1}$, $\omega_{sc2}+\omega_{m2}$, $\omega_{sc2}-\omega_{m2}$,

$2\omega_{sc1}$, $2\omega_{m1}$, $2\omega_{sc2}$, $2\omega_{m2}$,

$2\omega_{sc1}+\omega_{m1}$, $2\omega_{sc1}-\omega_{m1}$,

$2\omega_{sc2}+\omega_{m2}$, $2\omega_{sc2}-\omega_{m2}$

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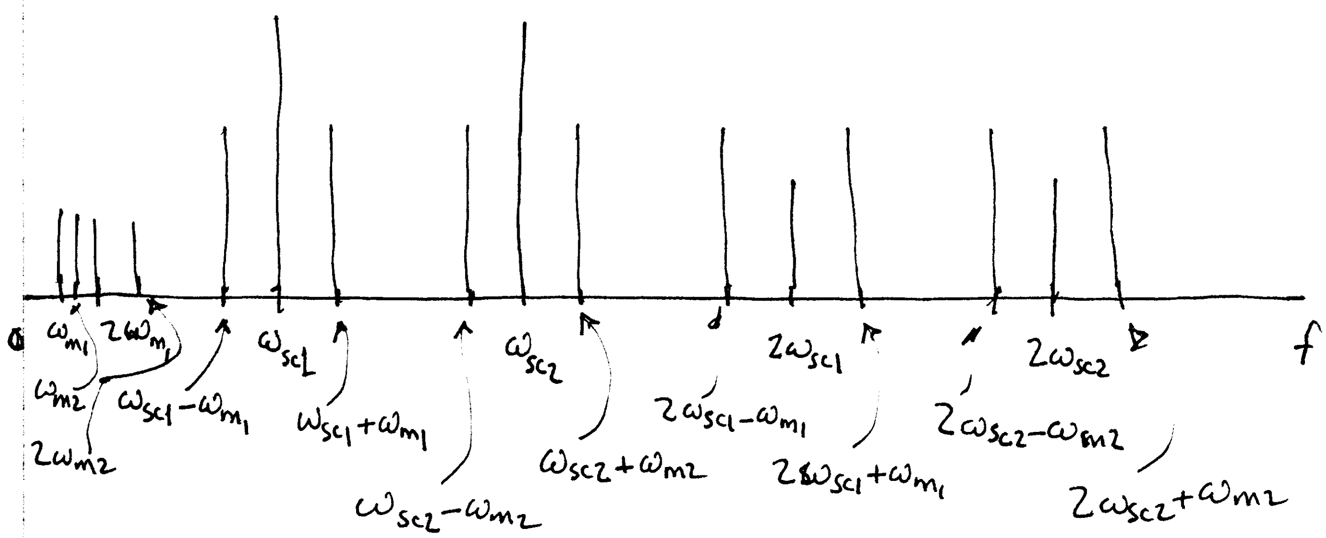
10.14 b

Freq	Peak Amplitude
$\omega_{sc1}, \omega_{sc2}$	$a i_{scp} + b i_{scp}^2$
ω_{m1}, ω_{m2}	$b i_{scp}^2 m'$
$\omega_{sc1} + \omega_{m1}$ $\omega_{sc1} - \omega_{m1}$ $\omega_{sc2} + \omega_{m2}$ $\omega_{sc2} - \omega_{m2}$	$\frac{1}{2} a i_{scp} m' + \frac{1}{2} b i_{scp}^2 (m')^2$
$2\omega_{sc1}, 2\omega_{m1}$ $2\omega_{sc2}, 2\omega_{m2}$	$\frac{1}{4} b i_{scp} (m')^2$
$2\omega_{sc1} + \omega_{m1}$ $2\omega_{sc1} - \omega_{m1}$ $2\omega_{sc2} + \omega_{m2}$ $2\omega_{sc2} - \omega_{m2}$	$\frac{1}{2} b i_{scp}^2 m'$



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10-14 c) Crosstalk is most likely to occur between the frequencies $(\omega_{sc1} + \omega_{m1})$ and $(\omega_{sc2} - \omega_{m2})$, because of the combination of amplitude and proximity in the frequency domain. (Crosstalk between ω_{m1} and ω_{m2} occurring directly is insignificant, as it will not appear as carrier modulation.)

Three measures that could be taken to reduce crosstalk between $(\omega_{sc1} + \omega_{m1})$ and $(\omega_{sc2} - \omega_{m2})$:

1) Increase the difference between ω_{sc1} and ω_{sc2}

2) Decrease the frequencies ω_{m1} and ω_{m2}.

3) Reduce the modulation factor(s) of ω_{m1} and/or ω_{m2} on their respective subcarriers.