Problem Solutions for Chapter 8

8-1. SYSTEM 1: From Eq. (8-2) the total optical power loss allowed between the light source and the photodetector is

$$P_T = P_S - P_R = 0\text{ dBm} - (-50\text{ dBm}) = 50\text{ dB}$$

$$= 2(l_c) + \alpha_f L + \text{system margin} = 2(1\text{ dB}) + (3.5\text{ dB/km})L + 6\text{ dB}$$

which gives L = 12 km for the maximum transmission distance.

SYSTEM 2: Similarly, from Eq. (8-2)

$$P_T = -13\text{ dBm} - (-38\text{ dBm}) = 25\text{ dB} = 2(1\text{ dB}) + (1.5\text{ dB/km})L + 6\text{ dB}$$

which gives L = 11.3 km for the maximum transmission distance.

8-2. (a) Use Eq. (8-2) to analyze the link power budget. (a) For the *pin* photodiode, with 11 joints

$$P_T = P_S - P_R = 11(l_c) + \alpha_f L + \text{system margin}$$

$$= 0\text{ dBm} - (-45\text{ dBm}) = 11(2\text{ dB}) + (4\text{ dB/km})L + 6\text{ dB}$$

which gives L = 4.25 km. The transmission distance cannot be met with these components.

(b) For the APD

$$0\text{ dBm} - (-56\text{ dBm}) = 11(2\text{ dB}) + (4\text{ dB/km})L + 6\text{ dB}$$

which gives L = 7.0 km. The transmission distance can be met with these components.

8-3. From $g(t) = (1 - e^{-2\pi Bt})\ u(t)$ we have

$$\left(1 - e^{-2\pi Bt_{10}}\right) = 0.1 \quad \text{and} \quad \left(1 - e^{-2\pi Bt_{90}}\right) = 0.9$$

so that

$$e^{-2\pi B t_{10}} = 0.9 \text{ and } e^{-2\pi B t_{90}} = 0.1$$

Then

$$e^{2\pi B t_r} = e^{2\pi B(t_{90}-t_{10})} = \frac{.9}{.1} = 9$$

It follows that

$$2\pi B t_r = \ln 9 \quad \text{or} \quad t_r = \frac{\ln 9}{2\pi B} = \frac{0.35}{B}$$

8-4. (a) From Eq. (8-11) we have

$$\frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(-\frac{t_{1/2}^2}{2\sigma^2}\right) = \frac{1}{2}\frac{1}{\sqrt{2\pi}\,\sigma} \qquad \text{which yields } t_{1/2} = (2 \ln 2)^{1/2}\,\sigma$$

(b) From Eq. (8-10), the 3-dB frequency is the point at which

$$G(\omega) = \frac{1}{2} G(0), \qquad \text{or} \qquad \exp\left[-\frac{(2\pi f_{3dB})^2\,\sigma^2}{2}\right] = \frac{1}{2}$$

Using σ as defined in Eq. (8-13), we have

$$f_{3dB} = \frac{(2 \ln 2)^{1/2}}{2\pi\sigma} = \frac{2 \ln 2}{\pi\, t_{FWHM}} = \frac{0.44}{t_{FWHM}}$$

8-5. From Eq. (8-9), the temporal response of the optical output from the fiber is

$$g(t) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(-\frac{t^2}{2\sigma^2}\right)$$

If τ_e is the time required for g(t) to drop to g(0)/e, then

$$g(\tau_e) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(-\frac{\tau_e^2}{2\sigma^2}\right) = \frac{g(0)}{e} = \frac{1}{\sqrt{2\pi}\,\sigma e}$$

from which we have that $\tau_e = \sqrt{2}\ \sigma$. Since t_e is the full width of the pulse at the 1/e points, then $t_e = 2\tau_e = 2\sqrt{2}\ \sigma$.

From Eq. (8-10), the 3-dB frequency is the point at which

$G(f_{3dB}) = \frac{1}{2}\ G(0)$. Therefore with $\sigma = t_e/(2\sqrt{2}\ )$

$$G(f_{3dB}) = \frac{1}{\sqrt{2\pi}}\ \exp\left[-\frac{1}{2}(2\pi f_{3dB}\ \sigma)^2\right] = \frac{1}{2}\frac{1}{\sqrt{2\pi}}$$

Solving for f_{3dB}:

$$f_{3dB} = \frac{\sqrt{2\ \ln 2}}{2\pi\sigma} = \frac{\sqrt{2\ \ln 2}}{2\pi}\frac{2\sqrt{2}}{t_e} = \frac{0.53}{t_e}$$

8-6. (a) We want to evaluate Eq. (8-17) for t_{sys}.

Using D_{mat} = 0.07 ns/(nm-km), we have

$$t_{sys} = \left\{(2)^2 + (0.07)^2(1)^2(7)^2 + \left[\frac{440(7)^{0.7}}{800}\right]^2 + \left[\frac{350}{90}\right]^2\right\}^{1/2}$$

= 4.90 ns

The data pulse width is $T_b = \frac{1}{B} = \frac{1}{90\text{ Mb/s}}$ = 11.1 ns

Thus $0.7T_b$ = 7.8 ns > t_{sys}, so that the rise time meets the NRZ data requirements.

(b) For q = 1.0,

$$t_{sys} = \left\{(2)^2 + (0.49)^2 + \left[\frac{440(7)}{800}\right]^2 + \left[\frac{350}{90}\right]^2\right\}^{1/2} = 5.85\text{ ns}$$

8-7. We want to plot the following 4 curves of L vs $B = \frac{1}{T_b}$:

(a) <u>Attenuation limit</u>

$P_S - P_R = 2(l_c) + \alpha_f L + 6$ dB, where $P_R = 9 \log B - 68.5$

so that $L = (P_S - 9 \log B + 62.5 - 2l_c)/\alpha_f$

(b) <u>Material dispersion</u>

$t_{mat} = D_{mat}\,\sigma_\lambda\, L = 0.7T_b$ or

$$L = \frac{0.7T_b}{D_{mat}\,\sigma_\lambda} = \frac{0.7}{BD_{mat}\,\sigma_\lambda} = \frac{10^4}{B} \quad \text{(with B in Mb/s)}$$

(c) <u>Modal dispersion</u> (one curve for q = 0.5 and one for q = 1)

$$t_{mod} = \frac{0.440L^q}{800} = \frac{0.7}{B} \quad \text{or} \quad L = \left[\left(\frac{800}{0.44}\right)\frac{0.7}{B}\right]^{1/q}$$

With B in Mb/s, L = 1273/B for q =1, and L = $(1273/B)^2$ for q = .5.

8-8. We want to plot the following 3 curves of L vs $B = \dfrac{1}{T_b}$:

(a) <u>Attenuation limit</u>

$P_S - P_R = 2(l_c) + \alpha_f L + 6$ dB, where $P_R = 11.5 \log B - 60.5$, $P_S = -13$ dBm, $\alpha_f =$ 1.5 dB/km, and $l_c = 1$ dB,

so that L = (39.5 - 11.5 log B)/1.5 with B in Mb/s.

(b) <u>Modal dispersion</u> (one curve for q = 0.5 and one for q = 1)

$$t_{mod} = \frac{0.440L^q}{800} = \frac{0.7}{B} \quad \text{or} \quad L = \left[\left(\frac{800}{0.44}\right)\frac{0.7}{B}\right]^{1/q}$$

With B in Mb/s, L = 1273/B for q =1, and L = $(1273/B)^2$ for q = .5.

8-9. The margin can be found from

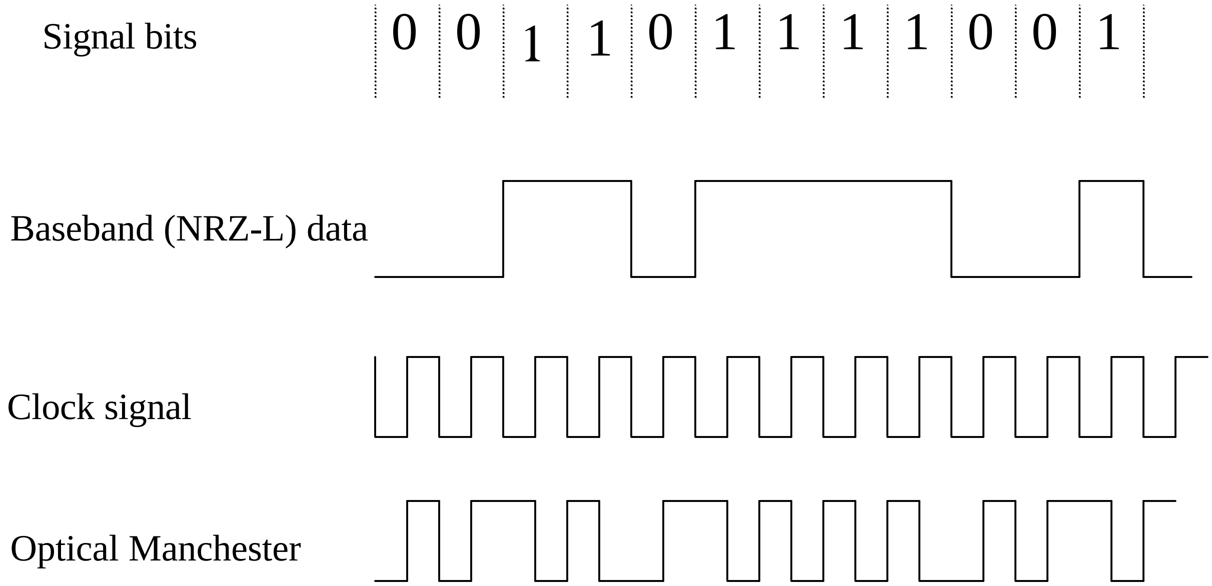
$P_S - P_R = l_c + 49(l_{sp}) + 50\alpha_f$ + noise penalty + system margin

-13 - (-39) = 0.5 + 49(.1) + 50(.35) + 1.5 + system margin

from which we have

system margin = 1.6 dB

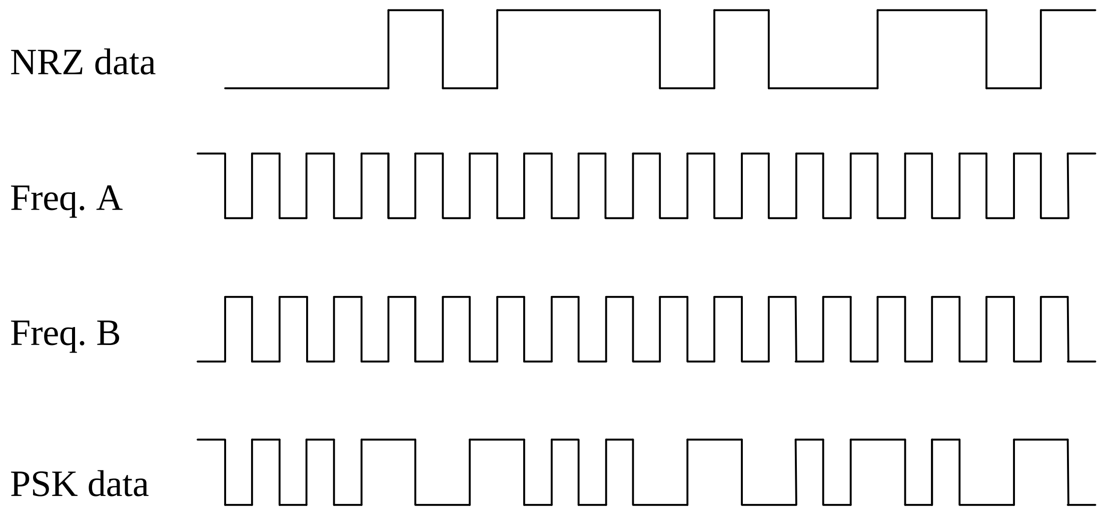
8-10. Signal bits



8-11. The simplest method is to use an exclusive-OR gate (EXOR), which can be implemented using a single integrated circuit. The operation is as follows: when the clock period is compared with the bit cell and the inputs are not identical, the EXOR has a high output. When the two inputs are identical, the EXOR output is low. Thus, for a binary zero, the EXOR produces a high during the last half of the bit cell; for a binary one, the output is high during the first half of the bit cell.

A	B	C
L	L	L
L	H	H
H	L	H
H	H	L

8-12.



8-13.

Original code	010	001	111	111	101	000	000	001	111	110
3B4B encoded	0101	0011	1011	0100	1010	0010	1101	0011	1011	1100

8-14. (a) For x = 0.7 and with Q = 6 at a 10^{-9} BER,

$P_{mpn} = -7.94 \log (1 - 18k^2\pi^4h^4)$ where for simplicity $h = BZD\sigma_\lambda$

(b) With x = 0.7 and k = 0.3, for an 0.5-dB power penalty at

140 Mb/s = 1.4×10^{-4} b/ps [to give D in ps/(nm.km)]:

$$0.5 = -7.94 \log \{1 - 18(0.3)^2[\pi(1.4\times10^{-4})(100)(3.5)]^4 D^4\}$$

or

$$0.5 = -7.94 \log \{1 - 9.097\times10^{-4} D^4\}$$ from which D = 2 ps/(nm.km)

B (Mb/s)	D [ps/(nm.km)]
140	2
280	1
560	0.5