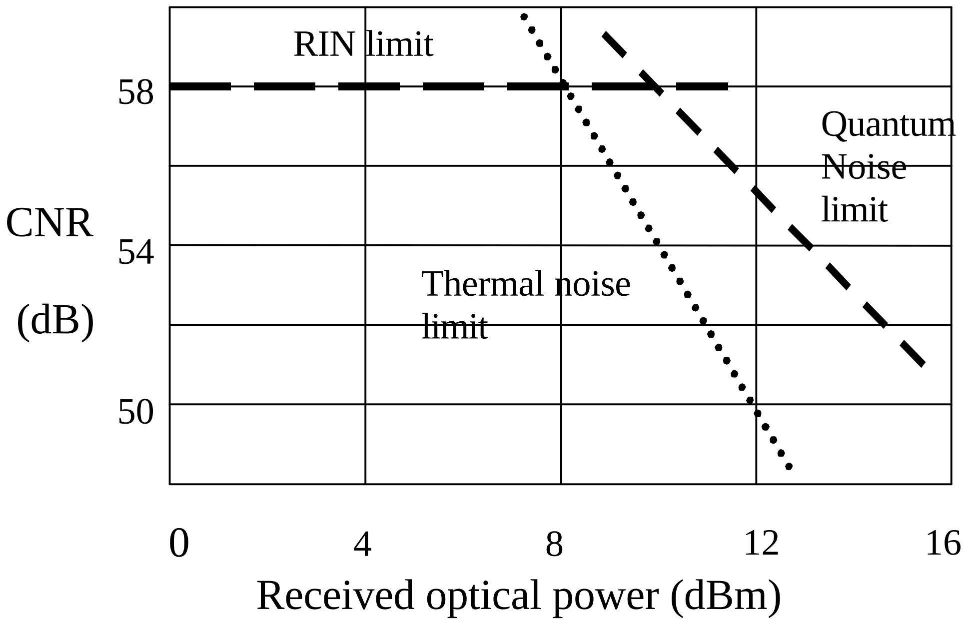
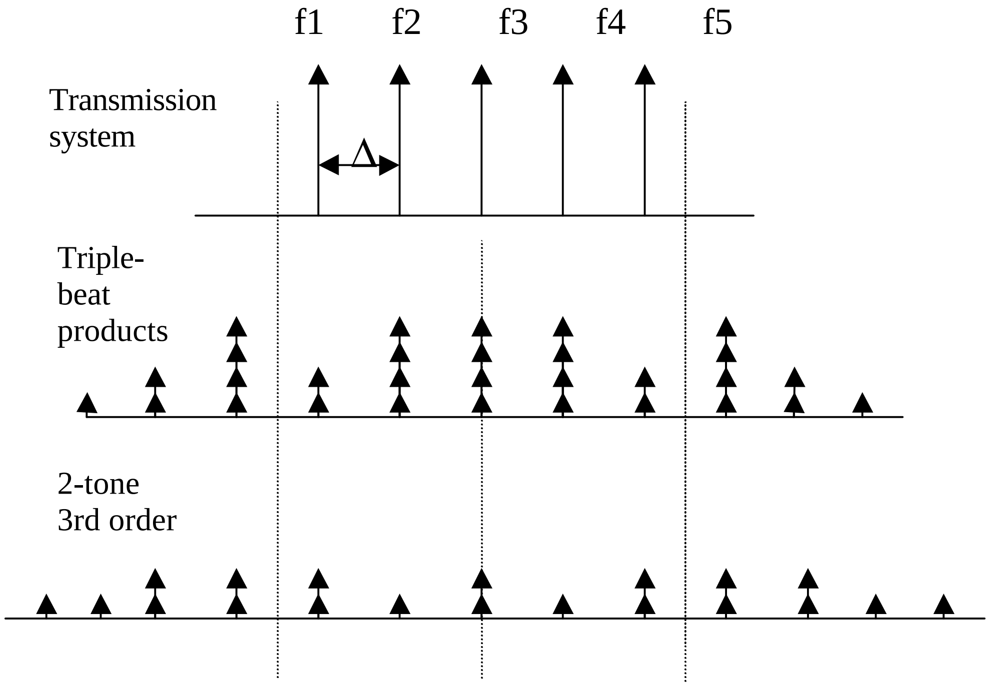
Problem Solutions for Chapter 9

9-1.



9-2.



9-3. The total optical modulation index is

$$m = \left[\sum_i m_i^2\right]^{1/2} = \left[30(.03)^2 + 30(.04)^2\right]^{1/2} = 27.4\ \%$$

9-4 The modulation index is $m = \left[\sum_{i=1}^{120} (.023)^2\right]^{1/2} = 0.25$

The received power is

$P = P_0 - 2(l_c) - \alpha_f L = 3\text{ dBm} - 1\text{ dB} - 12\text{ dB} = -10\text{ dBm} = 100\mu W$

The carrier power is

$$C = \frac{1}{2}(mR_0P)^2 = \frac{1}{2}(15\times10^{-6}\,A)^2$$

The source noise is, with RIN = -135 dB/Hz = 3.162×10^{-14} /Hz,

$$\langle i_{source}^2 \rangle = RIN\,(R_0P)^2 B = 5.69\times10^{-13}A^2$$

The quantum noise is

$$\langle i_Q^2 \rangle = 2q(R_0P + I_D)B = 9.5\times10^{-14}A^2$$

The thermal noise is

$$\langle i_T^2 \rangle = \frac{4k_BT}{R_{eq}} F_e = 8.25\times10^{-13}A^2$$

Thus the carrier-to-noise ratio is

$$\frac{C}{N} = \frac{\frac{1}{2}(15\times10^{-6}\,A)^2}{5.69\times10^{-13}\,A^2 + 9.5\times10^{-14}\,A^2 + 8.25\times10^{-13}\,A^2} = 75.6$$

or, in dB, C/N = 10 log 75.6 = 18.8 dB.

9-5. When an APD is used, the carrier power and the quantum noise change.

The carrier power is

$$C = \frac{1}{2}(mR_0MP)^2 = \frac{1}{2}(15\times10^{-5}\,A)^2$$

The quantum noise is

$$\langle i_Q^2 \rangle = 2q(R_0P + I_D)M^2F(M)B = 2q(R_0P + I_D)M^{2.7}B = 4.76\times10^{-10}A^2$$

Thus the carrier-to-noise ratio is

$$\frac{C}{N} = \frac{\frac{1}{2}(15\times10^{-5}\,A)^2}{5.69\times10^{-13}\,A^2 + 4.76\times10^{-11}\,A^2 + 8.25\times10^{-13}\,A^2} = 236.3$$

or, in dB, $\frac{C}{N}$ = 23.7 dB

9-6. (a) The modulation index is $m = \left[\sum_{i=1}^{32}(.044)^2\right]^{1/2} = 0.25$

The received power is P = -10 dBm = 100μW

The carrier power is

$$C = \frac{1}{2}(mR_0P)^2 = \frac{1}{2}(15\times10^{-6}\,A)^2$$

The source noise is, with RIN = -135 dB/Hz = 3.162×10^{-14} /Hz,

$$\langle i^2_{source} \rangle = RIN\,(R_0P)^2\,B = 5.69\times10^{-13}A^2$$

The quantum noise is

$$\langle i^2_{Q} \rangle = 2q(R_0P + I_D)B = 9.5\times10^{-14}A^2$$

The thermal noise is

$$\langle i^2_{T} \rangle = \frac{4k_BT}{R_{eq}}\,F_e = 8.25\times10^{-13}A^2$$

Thus the carrier-to-noise ratio is

$$\frac{C}{N} = \frac{\frac{1}{2}(15\times10^{-6}A)^2}{5.69\times10^{-13}A^2 + 9.5\times10^{-14}A^2 + 8.25\times10^{-13}A^2} = 75.6$$

or, in dB, C/N = 10 log 75.6 = 18.8 dB.

(b) When m_i = 7% per channel, the modulation index is

$$m = \left[\sum_{i=1}^{32}(.07)^2\right]^{1/2} = 0.396$$

The received power is P = -13 dBm = 50μW

The carrier power is

$$C = \frac{1}{2}(mR_0P)^2 = \frac{1}{2}(1.19\times10^{-5}A)^2 = 7.06\times10^{-11}A^2$$

The source noise is, with RIN = -135 dB/Hz = 3.162×10^{-14} /Hz,

$$\langle i^2_{source} \rangle = RIN\,(R_0P)^2\,B = 1.42\times10^{-13}A^2$$

The quantum noise is

$$\langle i_Q^2 \rangle = 2q(R_0P + I_D)B = 4.8\times10^{-14}A^2$$

The thermal noise is the same as in Part (a).

Thus the carrier-to-noise ratio is

$$\frac{C}{N} = \frac{7.06\times10^{-11}A^2}{1.42\times10^{-13}A^2 + 4.8\times10^{-14}A^2 + 8.25\times10^{-13}A^2} = 69.6$$

or, in dB, $C/N = 10 \log 69.6 = 18.4$ dB.

9-8. Using the expression from Prob. 9-7 with $\Delta\nu\tau = 0.05$, $f\tau = 0.05$, and $\Delta\nu = f = 10$ MHz, yields

$$\mathrm{RIN}(f) = \frac{4R_1R_2}{\pi}\,\frac{\Delta\nu}{f^2 + \Delta\nu^2}\left[1 + e^{-4\pi\Delta\nu\tau} - 2\,e^{-2\pi\Delta\nu\tau}\cos(2\pi f\tau)\right]$$

$$= \frac{4R_1R_2}{\pi}\,\frac{1}{20\text{ MHz}}\,(.1442)$$

Taking the log and letting the result be less than -140 dB/Hz gives

-80.3 dB/Hz + $10 \log R_1R_2 < -140$ dB/Hz

If $R_1 = R_2$ then $10 \log R_1R_2 = 20 \log R_1 < -60$ dB

or $10 \log R_1 = 10 \log R_2 < -30$ dB