1. MMF

$$\Delta T = \frac{(n_{core} - n_{clad})^2}{8c\, n_{core}} L$$

$$L = \frac{\Delta T\, 8c\, n_{core}}{(n_{core} - n_{clad})^2}$$

For a modal dispersion of 10% Tb $\Rightarrow \Delta T = 3,125ps$

$$L = \frac{(3,125ps)(8)(3\times 10^8 m/s)(1.48)}{(1.48-1.46)^2} = 27.8m$$

$$\boxed{L = 27.8m}$$

2. SMF

32 Gb/s w/ $\lambda = 1310nm$ $\Delta\lambda = 1nm$ $\bar{P} = 0.5mW$

SMF: Loss = 0.4dB/km $D = 0.5 \frac{ps}{nm\,km}$ $\bar{P}_{sens} = -23dBm$

a. Max Transmission Distance?

* Loss Limit Condition

$$\frac{\bar{P}_{TX}}{PP_{FIBER}} > \bar{P}_{RX,sens} \quad \text{Where } PP_{FIBER} = \text{Fiber Loss}$$

$$PP_{FIBER} < \frac{\bar{P}_{TX}}{\bar{P}_{RX\,sens}} = -3dBm - (-23dBm)$$

$$PP_{FIBER} < 20dB$$

$$L_{FIBER} < \frac{20dB}{0.4dB/km} \Rightarrow \text{Loss } L_{max} = 50km$$

* Dispersion Limit Condition $\Rightarrow \Delta T \leq \frac{1}{2B} = \frac{1}{2(32Gb/s)} = 15.6ps$

$$\Delta T = D\Delta\lambda L_{Max} \Rightarrow L_{MAX} = \frac{\Delta T}{D\Delta\lambda} = \frac{1}{2BD\Delta\lambda} = \frac{1}{2(32Gb/s)(0.5\frac{ps}{nm\,km})(1nm)}$$

Dispersion $L_{max} = 31.25km$

Max L = 31.25km, Dispersion Limited

b. $L = 5km \Rightarrow \Delta T = D\Delta\lambda L$

$$B = \frac{1}{2\Delta T} = \frac{1}{2D\Delta\lambda L} = \frac{1}{2(0.5\frac{ps}{nm\,km})(1nm)(5km)}$$

B = 200 Gb/s

3. Vertical p-i-n Detector

$W = 1\mu m \quad \alpha = 10^4 cm^{-1} \quad V_n = 10^5 m/s$

$R_{PD} = 20\Omega \quad C_{PD} = 70 fF$

a. $R = ?$ $\lambda = 1550nm$

$R = \eta \frac{q}{hc} \lambda$

$\eta = 1 - e^{-\alpha W} = 1 - e^{-(10^4 cm^{-1})(1\mu m)} = 0.632$

$$R = (0.632)(8\times10^5 \frac{A}{Wm})(1550nm) = 0.784 A/W$$

b. $BW = ?$

$$\text{Total } BW = \frac{1}{2\pi} \frac{1}{\frac{W}{V_n} + R_{PD}C_{PD}} = \frac{1}{2\pi} \frac{1}{\frac{1\mu m}{10^5 m/s} + (20\Omega)(70fF)}$$

$$\text{Total } BW = 14.0 GHz$$

4. Waveguide PD

$W = 340nm \quad \alpha = 10^3 cm^{-1} \quad \text{abs } L = 15\mu m$

$V_n = 10^5 m/s \quad R_{PD} = 50\Omega \quad C_{PD} = 10fF$

a. $R = ?$ $\lambda = 1550nm$

$$R = \eta \frac{q}{hc} \lambda$$

$$\eta = 1 - e^{-\alpha L_{abs}} = 1 - e^{-(10^3 cm^{-1})(15\mu m)} = 0.777$$

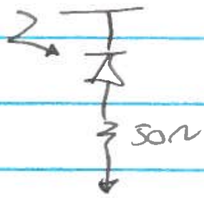
$$\boxed{R = (0.777)(8 \times 10^5 \, A/Wm)(1550nm) = 0.963 \, A/W}$$

b. $BW = ?$

$$\text{Total } BW = \frac{1}{2\pi} \frac{1}{\frac{W}{V_n} + R_{PD}C_{PD}} = \frac{1}{2\pi} \frac{1}{\frac{340nm}{10^5 m/s} + (50\Omega)(10fF)}$$

$$\boxed{\text{Total } BW = 40.8 \, GHz}$$

5. Rx Front-End Sensitivity for $BER = 10^{-12}$ 5a



$$i_{n,amp}^{rms} = \sqrt{\frac{4kT}{R} BW_n} = \sqrt{\frac{4(1.38\times10^{-23})(300)}{50}(22GHz)}$$

$$i_{n,amp}^{rms} = 2.7\mu A$$

a. p-i-n w/ $R = 1\ A/W$

$$\overline{P}_{sens,PIN} = \frac{Q\, i_{n,amp}^{rms}}{R} + \frac{Q^2 q\, BW_n}{R}$$

$$= \frac{(7.035)(2.7\mu A)}{1\ A/W} + \frac{(7.035)^2(1.6\times10^{-19})(22GHz)}{1\ A/W}$$

$$\boxed{\overline{P}_{sens,PIN} = 19.2\mu W = -17.2\ dBm}$$

$$i_{n,PIN,1}^{rms} = \sqrt{4q(1A/W)(19.2\mu W)(22GHz)} = 520nA$$

$$\boxed{i_{n,PIN,1}^{rms} = 520nA}$$

b. APD w/ $R = 1A/W$, $M = 8$, $F = 4$

$$\overline{P}_{sens,APD} = \frac{1}{M}\frac{Q\, i_{n,amp}^{rms}}{R} + F\frac{Q^2 q\, BW_n}{R}$$

$$= \frac{1}{8}\frac{(7.035)(2.7\mu A)}{1\ A/W} + 4\frac{(7.035)^2(1.6\times10^{-19})(22GHz)}{1\ A/W}$$

$$\boxed{\overline{P}_{sens,APD} = 3.07\mu W = -25.1\ dBm}$$

$$i_{n,APD,1}^{rms} = \sqrt{4(8^2)(4)q(1A/W)(3.07\mu W)(22GHz)} = 3.33\mu A$$

$$\boxed{i_{n,APD,1}^{rms} = 3.33\mu A}$$

5b

c. $\overline{P_{sens,OA}} = \frac{1}{G} \frac{Q\, i_{n,amp}^{rms}}{R} + \eta F \frac{Q^2 q\, BW_n}{R}$

$= \frac{1}{50} \frac{(7.035)(2.7\mu A)}{1\,A/W} + 2\, \frac{(7.035)^2 (1.6\times10^{-19})(22GHz)}{1\,A/W}$

$$\boxed{\overline{P_{sens,OA}} = 728nW = -31.4dBm}$$

$i_{n,OA,1}^{rms} = \sqrt{2(50)^2(4)q(1\,A/W)(728nW)(22GHz)} = 7.16\mu A$

$$\boxed{i_{n,OA,1}^{rms} = 7.16\mu A}$$