Homework 7

For problems 1-6 use the specification sheet for the PT10XGC pin optical receiver. Assume that the noise bandwidth is equal to the -3dB high frequency corner. Use the typical values given in the specification sheet.
http://www.bookham.com/documents/datasheets_rcvr/PT10XGC_14Feb07.pdf

1. What does PRBS stand for (see note 4)?
2. What is the quantum efficiency of the pin photodiode?
3. What is the shot noise if the receiver is operating at the minimum detectable power?
4. What is the thermal noise?
5. What is the noise equivalent power (NEP)?
6. What is the smallest possible minimum detectable power if the thermal noise is zero? This is called the quantum limited detection.

For problems 7-8 use the specification sheet for the ATV10GC APD.
http://www.bookham.com/documents/datasheets_rcvr/ATV10GC_14Feb07.pdf

7. Bookham also sells a similar receiver that uses an APD. If we assume that the thermal noise is the same as the pin receiver, what is the APD gain?
8. What the quantum limited detection of the APD receiver? Be sure to multiply the shot noise by the excess noise factor. See the APD users guide for more information on excess noise factor.

(1) PRBS: Pseudo random binary sequence

(2) $R = \eta \frac{q}{hf} = \eta \frac{\lambda}{1.24}$

$0.8 = \eta \frac{1.55}{1.24}$

$\boxed{\eta = 0.64}$

(3) $\sigma_{sh}^2 = 2q(RP + I_d)\Delta f$

$R = 0.8$

$P = -20.5\,dB = 8.91\,\mu W$

$\Delta f = 9\,GHz$

$\sigma_{sh}^2 = (2)(1.6\times10^{-19})((0.8)(8.91\times10^{-6}) + 10\times10^{-9})\ 9\times10^{9}$

$\sigma_{sh}^2 = 2.06\times10^{-14}$

$\boxed{\sigma_{sh} = 143\ nA}$

(4) $SNR = \frac{(RP)^2}{\sigma_{sh}^2 + \sigma_{th}^2}$

Assume $\sigma_{th}^2 \gg \sigma_{sh}^2$

$SNR = \frac{(RP)^2}{\sigma_{th}^2}$

We need the SNR

$BER = \frac{1}{2}\,erfc\left(\frac{Q}{\sqrt{2}}\right)$

$Q = \sqrt{2}\ erfc^{-1}(2\,BER)$

$Q = \sqrt{2}\ erfc^{-1}(2\times10^{-12})$

$Q = 7.03$

$SNR = Q^2$

$SNR = 49.5 = \frac{[(0.8)(8.91\times10^{-6})]^2}{\sigma_{th}^2}$

$\sigma_{th}^2 = 1.03\times10^{-12}$

$\boxed{\sigma_{th}^2 = 1.01\,\mu A}$ $\qquad 1.01\times10^{-6} \gg 143\times10^{-9}$

(5)

$$SNR = \frac{(R P_{in})^2}{[(R\,NEP)^2 + 2q R P_{in}]\,\Delta f}$$

Assume $(R\,NEP)^2 \gg 2q R P_{in}$

$$SNR = \frac{(R P_{in})^2}{(R\,NEP)^2\,\Delta f}$$

$$49.5 = \frac{(8.91\times10^{-6})^2}{NEP^2 \; 9\times10^9}$$

$$NEP = \frac{8.91\times10^{-6}}{\sqrt{(49.5)(9\times10^9)}}$$

$$\boxed{NEP = 13.3 \; \frac{pW}{\sqrt{Hz}}}$$ $1.33\times10^{-11}\ W/\sqrt{Hz}$

(6) if $\sigma_{th}^2 = 0$

$$49.5 = \frac{(R P_{in})^2}{2q\,(R P_{in} + I_d)\,\Delta f}$$

Assume $R P_{in} \gg I_d$

$$49.5 = \frac{R P_{in}}{2q\,\Delta f}$$

$$P_{in} = \frac{(49.5)(2)(1.6\times10^{-19})(9\times10^9)}{0.8}$$

$P_{in} = 178\ nW = -37.5\ dBm$ $\quad R P_{in} = 142.6\ nA \gg 10\ nA$

(7) $\sigma_{th}^2 = 1.03\times10^{-12}$ for $\Delta f = 9GHz$ for $\Delta f = 7.5GHz$ $\sigma_{th}^2 = 8.58\times10^{-13}$

$$SNR = \frac{(R M P_{min})^2}{\sigma_{th}^2 + 2q(I_d + RP_{min} M^2 F)\Delta f}$$

$$F = kM + (1-k)(2 - \tfrac{1}{M})$$

Assume $\sigma_{th}^2 \gg 2q\, RP_{min} M^2 F\, \Delta f$

$R = 0.8$

$P_{min} = -26.5\ dBm = 2.24\ \mu W$

$$49.5 = \frac{[(0.8)(M)(2.24\times10^{-6})]^2}{1.03\times10^{-12}}$$

$$M = \frac{\sqrt{(49.5)(1.03\times10^{-12})}}{(0.8)(2.24\times10^{-6})}$$

$\boxed{M = 3.98}$

check assumption

$F = (0.45)(4) + (1-0.45)(2 - \tfrac{1}{4})$
$= 2.76$

$\sigma_{sh}^2 = (2)(1.6\times10^{-19})(100\times10^{-9} + (0.8)(2.24\times10^{-6})(4)^2(2.76))(7.5\times10^9)$
$= 1.9\times10^{-13} < 1.03\times10^{-12}$
but barely

see plot for more accurate M

$\boxed{M = 4.03}$

(8) $\sigma_{th}^2 = 0$

$$SNR = \frac{(\cancel{R}\cancel{M}P_{in})^{\cancel{2}}}{2q(\cancel{I_d} + \cancel{R}\cancel{P_{in}}\cancel{M^2}F)\Delta f}$$

$P_{in} = (SNR)(2q)\,F\Delta f$

$= (49.5)(2)(1.6\times10^{-19})(2.76)(7.5\times10^9)$

$P_{min} = 328\,nW$

$P_{min} = -34.8\ dBm$