Problem 1) : (30 points)

a) What is a direct detection system

Optical Beam → Detector → Photocurrent ∝ intensity

2 Optical Signal Detected and converted to a current.

b) What is a heterodyne detection system?

Optical Signal + Local Oscillator → Photocurrent

Signal + Local Oscillator beams impingent on a detector

3 Photocurrent component at the frequency which is the difference between the signal and local oscillator frequencies is amplified and used to extract signal

c) What is meant by a heterodyne ASK system?

heterodyne system which which is used to detect

2 signals which are simply different in amplitudes (digital)

d) What is implied by a CDMA communication system? Give an example.

CDMA stands for code-division multiple access. In contrast to FDM/WDM or TDM, CDMA gives each user an extremely long pseudo-random code. All codes are statistically uncorrelated; or in linear algebra the

5 the inner-product of any two codes is 0 unless the two codes are the same (i.e., orthogonal vectors). The message that one wants to transmit is modulated with the assigned code. In order to demodulate message is multiplied by the same code. CDMA is the dominant technology behind U.S.

μ m, what is the output photocurrent from the detector? What is the " square of the shot noise current " per unit band-width?

$$I_{ph} = \eta \frac{P_{opt}}{hf} e = \frac{.8 \times 1\times10^{-3}\,W}{6.64\times10^{-34}\,J\,sec \; \frac{3\times10^{8}\,m/s}{1\times10^{-6}\,m}} (1.6\times10^{-19})\,C = .64\,mA$$

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$$\langle i_{sh}\rangle^2 = 2eI_{ph}\Delta f$$

$$\frac{\langle i_{sh}\rangle^2}{\Delta f} = 2(1.6\times10^{-19}\,Coul)(6.44\times10^{-4}\,A) = 2.06\times10^{-22}\,A/Hz$$

The photocurrent in a PIN diode is 100 μ A. The load resistance through which this current flows is 100 ohms; the temperature of the resistor is 300 K. The voltage developed across the load resistance is applied to the input of an FET preamplifier having equivalent noise voltage and current sources at the input equal to, $1.0 \cdot 10^{-9}$ volts per $\sqrt{Hz}$ and $1.2 \cdot 10^{-13}$ amp / $\sqrt{Hz}$. The bandwidth is 500 MHz. The amplifier is equalized and the bandwidth is RC limited.

a) What is the total rms noise voltage referred to the input of the amplifier?

b) What is the signal to noise ratio?

c) Assuming Gaussian noise, estimate the best bit-error rate possible? b) So a 10 psec/km/nm fiber gives what bandwidth at one micron?

a) Note Amplifier is equalized (M = 1, F = 1 since PIN Diode)

$$V_N^2 = \left(\Delta f + \frac{4\pi^2}{3}(\Delta f)^3 C^2 R^2\right)(V_A^*)^2 + 2eI\Delta f R^2 + 4KT\Delta f R + \Delta f R^2 (I_A^*)^2$$

Bandwidth limited so $\Delta f = \frac{1}{2\pi RC}$ or $RC = \frac{1}{2\pi \Delta f}$; Thus

$$V_N^2 = \frac{4}{3}\Delta f (V_A^*)^2 + 2eI\Delta f R^2 + 4kT\Delta f R + \Delta f R^2 (I_A^*)^2$$

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$$V_N^2 = \frac{4}{3}(500\times10^6\ Hz)\left(1\times10^{-9}\ \frac{V}{\sqrt{Hz}}\right)^2 + 2(1.6\times10^{-19}\ C)(100\times10^{-6}\ A)(500\times10^6\ Hz)(100\ \Omega)^2$$
$$+ 4\left(1.38\times10^{-23}\ \frac{J}{K}\right)(300\ K)(500\times10^6\ Hz)(100\ \Omega)$$
$$+ (500\times10^6\ Hz)(100\ \Omega)^2\left(1.2\times10^{-13}\ \frac{A}{\sqrt{Hz}}\right)^2$$

$V_N^2 = 1.65\times10^{-9}\ V^2$ Dominated by Thermal + Amplifier Noise

b) $\frac{V_s}{V_N} = \frac{100\times10^{-6}\ A \times 100\ \Omega}{[1.65\times10^{-9}\ V^2]^{1/2}} \simeq 250$

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c) $BER = \text{erfc}\left(\frac{k}{2\sqrt{2}}\right) = \text{erf}(\approx 250) \approx 0$ (large signal)

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b) Fiber Bandwidth $= \frac{1}{2\pi \Delta T_p}$ $\Delta T_p = DL\Delta\lambda$ (10 psec/nm/km)

$\therefore \Delta T_p = 10\times10^{-12}(.00166)\ km^{-1}\ sec$

$= 1.66\times10^{-14}\ \frac{sec}{km}$

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$\frac{\Delta\lambda}{\lambda} = -\frac{\Delta f}{f} \Rightarrow \Delta\lambda = -\frac{\lambda^2}{c}\Delta f$

$\Delta\lambda = \frac{(1\times10^{-6})^2 \times 500\times10^6}{3\times10^8}$

$\simeq 166\times10^{-14}\ m = .00166\ nm$

$\therefore$ Fiber bandwidth $= \left(\frac{1}{2\pi\times1.66}\times10^{14}\right) sec^{-1}\ km$

Problem 3) (30 points)

A digital optical transmission system is desired to send at a rate of 6 Gbit/sec. The link is 10 km long with the dispersion of the optical fiber equal to 10 psec/nm/km. The total fiber loss is 1 db / km. A semiconductor laser at 1 micron having a power of 1 mwatt with a risetime of .1 nsec. is used. The receiver is known to be shot noise limited with M = 50, F = 6, total input R = .1 kΩ, and total input C = .3 pF. (an APD detector with a .9 quantum efficiency)

a) What is the signal to noise ratio in the receiver?

$\Delta f = \frac{B}{2} = 3\times10^{9}$ Hz

loss 1 dB/km → Power at Detector = .1 mwatt

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$M(I_{sig}) = M\frac{P_{opt}}{hf}e\eta = 50\frac{10^{-4}}{6.64\times10^{-34}\frac{10^{-6}}{3\times10^{8}}}\times(1.6\times10^{-19})(0.9) \cong 36\times10^{-4}$ A

shot Noise Limited so $k = \frac{I_{sg}}{\sqrt{\Delta f\, 2eI_{sg}F}} = \left(\frac{I_{sg}}{2e\Delta f F}\right) = \left(\frac{7.2\times10^{-5}}{3\times10^{9}\times2\times1.6\times10^{-19}\times6}\right)^{1/2}$

$\cong 110$

b) Can the bit rate be transmitted over the fiber? Show numbers

① Check channel capacity

$C = \Delta f \lg_2\left(1+\frac{S}{N}\right) = 3\times10^{9}\lg_2(1+110) \cong 10^{10}$ B/sec

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② $B = 2\Delta f$ $\quad 2\frac{1}{2\pi RC} = \frac{1}{\pi\times100\times.3\times10^{-12}} = 10.6$ GB/sec

small ≅ $RC = 3\times10^{-10}$ sec

③ $\tau_T^2 = \tau_s^2 + \tau_f^2 + \tau_D^2$ $\quad \tau_F \cong 10\times0.033\times10 = 3.3$ psec since

Determining $\tau_T = ((.1\times10^{-9})^2 + (3.3\times10^{-12})^2) \cong 10^{-10} \cong .1$ nsec $\quad \Delta\lambda = -\frac{\lambda\Delta f}{f} = -\frac{\lambda^2\Delta f}{c} = .033$ nm

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c) What is the average shot noise current out of the APD?

$\frac{1}{\tau_T} \cong 100$ Gb/sec > 6 Gb/sec

$\frac{P_{opt}}{hf}e\eta$

$i_{shot} = (2eI_{sig}\Delta f\, M^2F)^{1/2}$

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$= (2(1.6\times10^{-19})(6)(7.2\times10^{-5})\times3\times10^{9})^{1/2}\, 50 = 3.2\times10^{-5}$ amps (M)

+1 for having M^2F