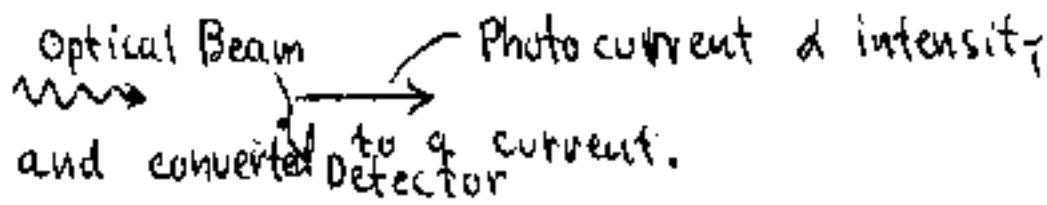
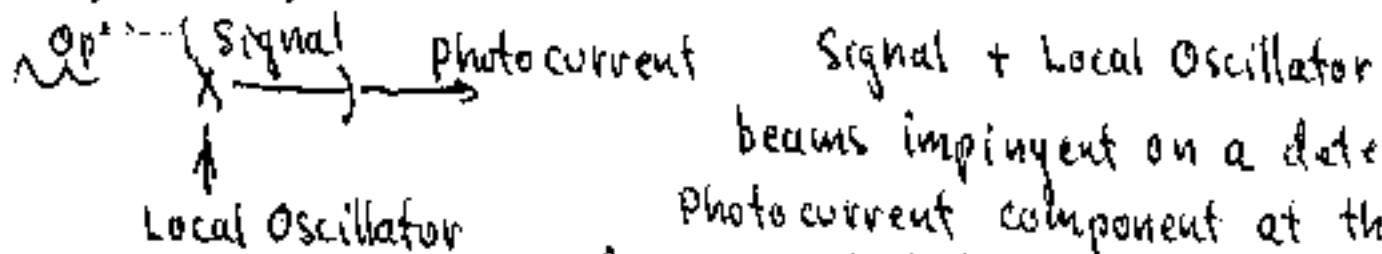


Problem 1) : (30 points)

a) What is a direct detection system



b) What is a heterodyne detection system?



c) What is meant by a heterodyne ASK system?

heterodyne system which which is used to detect signals which are simply different in amplitudes (digital)

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

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

$$I_{ph} = \eta \frac{P_{opt}}{hf} e = .8 \times \frac{1 \times 10^{-3} \text{ W}}{6.64 \times 10^{-34} \text{ J-sec} \times \frac{3 \times 10^8 \text{ m/s}}{1 \times 10^{-6} \text{ m}}} (1.6 \times 10^{-19}) \text{ C} = 64 \text{ mA}$$

$$(i_{sh})^2 = 2eI_{ph}\Delta f$$

$$\frac{(i_{sh})^2}{\Delta f} = 2(1.6 \times 10^{-19} \text{ Coul}) (6.4 \times 10^{-4} \text{ A}) = 2.04 \times 10^{-22} \text{ A}^2/\text{Hz}$$

The photocurrent in a PIN diode is $100 \mu A$. The load resistance through which this current flows is 100Ω ; 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)

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

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

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

$$V_N^2 = \frac{4}{3} (500 \times 10^6 \text{ Hz}) \left(1 \times 10^{-9} \frac{V}{\sqrt{Hz}} \right)^2 + 2(1.6 \times 10^{-19} C)(100 \times 10^{-6} A)(500 \times 10^6 \text{ Hz}) (100 \Omega)^2 + 4(1.38 \times 10^{-23} \frac{J}{K}) (300 K)(500 \times 10^6 \text{ Hz})(100 \Omega) + (500 \times 10^6 \text{ Hz})(100 \Omega)^2 (1.2 \times 10^{-13} \frac{A}{\sqrt{Hz}})^2$$

$$V_N^2 = 1.65 \times 10^{-9} \text{ V}^2 \quad \text{Dominated by Thermal + Amplifier Noise}$$

$$b) \frac{V_s}{V_N} = \frac{100 \times 10^{-6} A \times 100 \Omega}{[1.65 \times 10^{-9} \text{ V}^2]^{1/2}} \approx 250$$

$$c) BER = \text{erfc} \left(\frac{k}{2\sqrt{21}} \right) = \text{erfc}(250) \approx 0 \quad (\text{large signal})$$

$$b) \text{ Fiber Bandwidth} = \frac{1}{2\pi\Delta T_p}$$

$$\therefore \Delta T_p = 10 \times 10^{-12} (0.00166) \text{ km}^{-1} \text{ sec} = 1.66 \times 10^{-14} \frac{\text{sec}}{\text{km}}$$

$$\Delta T_p = DL\Delta\lambda \quad \text{10 psec/nm/km}$$

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

$$\Delta\lambda = \frac{(1 \times 10^{-6})^2 \times 500 \times 10^6}{3 \times 10^8}$$

$$\approx 166 \times 10^{-14} \text{ m} = 100166 \text{ nm}$$

$$\therefore \text{Fiber bandwidth} = \left(\frac{1}{2\pi \times 1.66} \times 10^{14} \right) \text{ sec}^{-1} \text{ km}$$

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 $R = .1 \text{ k}\Omega$, and total input $C = .3 \text{ pF}$. (an APD detector with a .9 quantum efficiency)

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

$$\Delta f = \frac{B}{2} = 3 \times 10^9 \text{ Hz}$$

loss: 1 dB/km \rightarrow Power at Detector = .1 mwatt

$$M(I_{sig}) = M \frac{P_{opt}}{hf} e\eta = 50 \frac{10^{-6}}{6.64 \times 10^{-34} \times 3 \times 10^8} \times (1.6 \times 10^{-19}) (0.9) = 36 \times 10^{-9} \text{ A}$$

shot noise limited so

$$k = \frac{I_{sig}}{\sqrt{\Delta f 2e I_{sig} F}} = \left(\frac{I_{sig}}{2e \Delta f F} \right)^{1/2} = \left(\frac{7.2 \times 10^{-5}}{3 \times 10^9 + 2 \times 1.6 \times 10^{-19} \times 6} \right)^{1/2} \approx 110$$

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

① Check channel capacity

$$C = \Delta f \log_2 \left(1 + \frac{S}{N} \right) = 3 \times 10^9 \log_2 (1 + 110) \approx 10^{10} \text{ B/sec}$$

② $B = 2\Delta f$

$$\frac{1}{2\pi RC} = \frac{1}{\pi \times 100 \times 3 \times 10^{-12}} = 10.6 \text{ GB/sec}$$

Small $\approx RC = 3 \times 10^{-10} \text{ sec}$

③ $\sigma_T^2 = \sigma_s^2 + \sigma_f^2 + \sigma_D^2$

$$\sigma_f = 10 \times 0.033 \times 10 = 3.3 \text{ psec since}$$

Determining $\sigma_T = \left((1 \times 10^{-9})^2 + (3.3 \times 10^{-12})^2 \right)^{1/2} \approx 10^{-9} \approx .1 \text{ nsec}$ $\Delta \lambda = -\frac{\lambda \Delta f}{f} = -\frac{\lambda^2 \Delta f}{c} = .033 \text{ nm}$

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

$$\frac{1}{\sigma_T} \approx 100 \text{ Gb/sec} > 6 \text{ Gb/sec}$$

$$I_{shot} = \left(2e I_{sig} \Delta f M^2 F \right)^{1/2}$$

$$= \left(2(1.6 \times 10^{-19})(6) \times 7.2 \times 10^{-5} \times 3 \times 10^9 / 50 \right)^{1/2} = 3.2 \times 10^{-5} \text{ amps}$$

+1 for having $M^2 F$