

## ENEE 408E Design Problem Set 6

Due Friday December 12, 2003

A problem very much like (1) (2) or (3) will be on the final examination

(1) A point source of light that emits 1W of light at 600nm is placed on axis 50mm from the end face of a single mode fiber with core diameter  $5\mu\text{m}$ ,  $n_1 = 1.46$ ,  $n_2 = 1.45$ . Calculate:

(a) The N.A. of the fiber.

(b) Is the fiber single mode at this wavelength?

(c) If the fiber is not single mode, what wavelength would be needed to ensure this?

(d) Use a simple ray model to calculate the power that is guided in the fiber.

(2) A photomultiplier (PMT) has a dark noise level of 100 pulses per second. Calculate the minimum optical power ( $S/N=1$ ) at 500nm that can be detected with a 10 second integration time. Assume that the quantum efficiency of the PMT is 0.2 at 500nm.

(3) A p-i-n photodiode has responsivity  $0.8\text{A/W}$  at  $1.55\mu\text{m}$ . The effective resistance of the detector circuit is  $50\text{ohm}$ . The photodiode dark current is  $1\text{pA}/\sqrt{\text{Hz}}$ . Calculate the NEP at 300K of the detector. Include both shot noise and Johnson noise in your calculation. If the area of the detector is  $1\text{mm}^2$  what is its detectivity?

(4) How would the answer to question (3) be modified if the detector were feeding an amplifier with a noise temperature of 600K?

(5) Use the World Wide Web to find a photodetector that provides performance better than 1 GHz at  $1.55\mu\text{m}$ . Print out the data sheet and identify responsivity, quantum efficiency, detector time constant, dark current and NEP.

## ENEE 408E Design Problems 6. Solutions

(1)  $P := 1$  Power

$\lambda := 600 \cdot 10^{-9}$  wavelength

$D := 5 \cdot 10^{-6}$  core diameter

$n_1 := 1.46$   $n_2 := 1.45$

$R := 50 \cdot 10^{-3}$

$A := \frac{\pi \cdot D^2}{4}$  area of fiber core

(a)  $NA := \sqrt{n_1^2 - n_2^2}$

$NA = 0.171$

(b) From Eq. (17.49) in the book

$\frac{D}{2 \cdot \lambda} = \frac{m}{4 \cdot NA}$  d in the book is  $D/2$

$m := 4 \cdot NA \cdot \frac{D}{2 \cdot \lambda}$

$m = 2.843$   $m \geq 1$  so fiber is not single mode

(c) For single mode, set  $m=1$

$\lambda := \frac{4 \cdot NA \cdot D}{2}$

$\lambda = 1.706 \times 10^{-6}$

Need  $\lambda > 1.706 \mu\text{m}$

(d) Source is far from fiber, use approximation for solid angle

$\delta\omega := \frac{A}{R^2}$

Power in is  $P_{in} := P \cdot \frac{\delta\omega}{4 \cdot \pi}$

$P_{in} = 6.25 \times 10^{-10}$  Power guided in fiber is 0.625nW.



$$i_d := 10^{-12} \quad \text{dark current for } \Delta f=1$$

$$\text{shot} = 2 \cdot e \cdot \text{Resp} \cdot \text{NEP} + 2 \cdot e \cdot i_d \quad \text{shot noise for } \Delta f=1$$

$$\text{johanson} := 4 \cdot \frac{k \cdot T}{R} \quad \text{Johnson noise}$$

$$i_s = \text{Resp} \cdot \text{NEP}$$

$$\frac{S}{N} = \frac{(\text{Resp} \cdot \text{NEP})^2}{2 \cdot e \cdot \text{Resp} \cdot \text{NEP} + 2 \cdot e \cdot i_d + \text{johanson}}$$

Set signal to noise ratio =1 and solve for NEP

$$\frac{(\text{Resp} \cdot \text{NEP})^2}{2 \cdot e \cdot \text{Resp} \cdot \text{NEP} + 2 \cdot e \cdot i_d + \text{johanson}} = 1$$

$$\text{NEP} := \frac{\left[ e \cdot c + \left( e \cdot c^2 + 2 \cdot e \cdot c \cdot i_d + \text{johanson} \right)^{\left( \frac{1}{2} \right)} \right]}{\text{Resp}} \quad \text{Noise equivalent power}$$

$$\text{NEP} = 2.275 \times 10^{-11} \quad \text{Watts/root Hz}$$

Johnson noise is dominant

$$A := 0.1^2 \quad \text{Area in square centimeters}$$

$$D := \frac{\sqrt{A}}{\text{NEP}} \quad D = 4.396 \times 10^9 \quad \text{Detectivity in units of cm root(Hz)/Watt}$$

(4) For an amplifier with a noise temperature of 600K the noise figure is

$$F_N := 1 + \frac{600}{300}$$

$$F_N = 3$$

The Johnson noise is multiplied by this factor, we usually assume that it is only the Johnson noise that is increased by the noise figure, since the shot noise comes in with the signal.

$$\text{johanson} := F_N \cdot \text{johanson}$$

$$\text{NEP} := \frac{\left[ e \cdot c + \left( e \cdot c^2 + 2 \cdot e \cdot c \cdot i_d + \text{johanson} \right)^{\left( \frac{1}{2} \right)} \right]}{\text{Resp}}$$

$$\text{NEP} = 3.94 \times 10^{-11} \quad \text{Noise equivalent power in } W/\sqrt{\text{Hz}}$$