Texas A&M University
Department of Electrical and Computer Engineering

ECEN 689 – Optical Interconnects

Spring 2020

Exam #1

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are **5** pages in your exam
- You may use one double-sided page of notes and equations for the exam
- Good Luck!

Problem	Score	Max Score
1		50
2		50
Total		**100**

Name: SAM PALERMO

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Table 4.1 Numerical relationship between Q and bit-error rate.

Q	BER	Q	BER
0.0	1/2	5.998	10^{-9}
3.090	10^{-3}	6.361	10^{-10}
3.719	10^{-4}	6.706	10^{-11}
4.265	10^{-5}	7.035	10^{-12}
4.753	10^{-6}	7.349	10^{-13}
5.199	10^{-7}	7.651	10^{-14}
5.612	10^{-8}	7.942	10^{-15}

Table 4.6 Numerical values for BW_n and BW_{n2}.

$H(f)$	BW_n	BW_{n2}
1st-order low pass	$1.57 \cdot BW_{3dB}$	∞
2nd-order low pass, crit. damped ($Q = 0.500$)	$1.22 \cdot BW_{3dB}$	$2.07 \cdot BW_{3dB}$
2nd-order low pass, Bessel ($Q = 0.577$)	$1.15 \cdot BW_{3dB}$	$1.78 \cdot BW_{3dB}$
2nd-order low pass, Butterworth ($Q = 0.707$)	$1.11 \cdot BW_{3dB}$	$1.49 \cdot BW_{3dB}$
Brick wall low pass	$1.00 \cdot BW_{3dB}$	$1.00 \cdot BW_{3dB}$
Rectangular (impulse response) filter	$0.500 \cdot B$	∞
NRZ to full raised-cosine filter	$0.564 \cdot B$	$0.639 \cdot B$

Problem 1 (50 points)

A system utilizes a transmitter that has an average power of 1mW signaling over a high-performance multi-mode fiber channel with loss of 3dB/km and a bandwidth-distance product of 3GHz*km. Assuming a receiver sensitivity of $\bar{P}_{sens} = -10dBm$, what is the maximum loss-limited transmission distance at low data rates? Assuming that the required fiber bandwidth is 0.75*(Data Rate), what is the maximum data rate at this maximum transmission distance?

Loss-limited transmission distance $L_{max} = \dfrac{\bar{P}_{TX}(dBm) - \bar{P}_{sens}(dBm)}{\text{Fiber loss (dB/km)}}$

$$L_{max} = \frac{0dBm - (-10dBm)}{3dB/km} = \frac{10dB}{3dB/km} = 3.33km$$

$$\text{Data Rate} = \frac{\text{Fiber BW}\cdot D}{0.75} = \frac{3GHz\cdot km}{0.75\,(3.33km)} = 1.2Gb/s$$

Lmax = 3.33km

Max Data Rate at Lmax = 1.2Gb/s

If this system now operates at 25Gb/s with the same conditions, what is the maximum transmission distance?

$$\text{Max Distance} = \frac{\text{Fiber BW}\cdot D}{0.75\,(DR)} = \frac{3GHz\cdot km}{0.75\,(25Gb/s)} = 160m$$

Lmax (DR=25Gb/s) = 160m

Problem 2 (50 points)
An optical receiver utilizes an InGaAs vertical p-i-n detector that has an absorption coefficient $\alpha = 2 \times 10^{4} cm^{-1}$ when operating at λ=980nm. The device is biased to yield carrier velocities of 10^5m/s and electrical parasitics of R_{PD}=10Ω and C_{PD}=50fF.

a) What is the maximum possible intrinsic layer width W to achieve 25GHz bandwidth? Under this condition, what responsivity R is achieved?

$$BW = \frac{1}{2\pi} \cdot \frac{1}{\frac{W}{v_n} + R_{PD}C_{PD}}$$

$$W = \left(\frac{1}{2\pi BW} - R_{PD}C_{PD}\right)v_n = \left[\frac{1}{2\pi(25GHz)} - (10\Omega)(50fF)\right]10^5 m/s$$

$$W = 587nm$$

$$R = \left(1 - e^{-\alpha W}\right)\frac{q}{hc}\lambda$$

$$= \left[1 - e^{-(2\times10^4 cm^{-1})(587nm)}\right]\left(8\times10^5 \frac{A}{mW}\right)(980nm)$$

$$= 0.542\ A/W$$

W (BW=25GHz) = 587nm

R = 0.542 A/W

The receiver utilizes a simple front-end that consists of a 100Ω resistor and has a noise bandwidth BW_n=25GHz. Give the optical average power sensitivity for a BER=10^{-12} considering both amplifier and detector noise. Assume T=300K.

$$i_{n,amp}^{rms} = \sqrt{\frac{4KT}{R} BW_n} = \sqrt{\frac{4(1.38\times10^{-23})(300K)}{100\Omega}(25GHz)} = 2.03\mu A_{rms}$$

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

$$= \frac{(7.035)(2.03\mu)}{0.542} + \frac{(7.035)^2(1.6\times10^{-19})(25G)}{0.542} = 26.7\mu W$$

$\bar{P}_{sens}$ = 26.7μW

= −15.7dBm

Scratch Paper