NAVAL POSTGRADUATE SCHOOL
Monterey, California

EC 3550 FINAL EXAM 6/97 Prof. Powers

- This exam is open book and notes.
- There are five problems; each is equally weighted.
- Partial credit will be given; be sure to do some work on each problem.
- Be sure to include units in your answers.
- Please circle or underline your answers.
- Show *ALL* work.
- Write only your name on this sheet.
- Exams and course grades *should* be available outside the Optical Electronics Laboratory (Bu 224) on **Monday morning, 23 June**.
- The originals or copies of this exam and/or its solutions are not to be given or lent to anyone else.

Course grade: ______________

1		4	
2		5	
3			
TOTAL			

Name: ______________________________

FIBER SPECIFICATIONS

	Fiber #1	Fiber #2	Fiber #3	Fiber #4
Size	50/125	62.5/125	10/125	100/140
g	1.90	∞	∞	1.78
NA	0.22 (at $r = 0$)	0.20	0.09	0.18 (at $r = 0$)
α @ 850 nm	2.0 dB/km	1.0 dB/km	1.2 dB/km	5.0 dB/km
α @ 1300 nm	1.0 dB/km	0.8 dB/km	0.7 dB/km	2.0 dB/km
α @ 1550 nm	0.6 dB/km	0.4 dB/km	0.4 dB/km	0.8 dB/km

SOURCE SPECIFICATIONS

	Laser #1	Laser #2	LED #3	Laser #4
Wavelength	850 nm	1300 nm	850 nm	1550 nm
$\Delta\lambda$	0.5 nm	1.0 nm	25 nm	1.1 nm
Power at pigtail end	0.70 mW	0.8 mW	60 μW	2.0 dBm
Pigtail size	62.5/125 μm	10/125 μm	200/300 μm	8/125 μm
Pigtail NA	0.20	0.12	0.25	0.10
Pigtail type	Step index	Step index	Step index	Step index

DETECTOR SPECIFICATIONS

	Detector #1	Detector #2	Detector #3
Material	Silicon	Germanium	InGaAs
Responsivity A/W @ $M = 1$	0.8 @ 850 nm	0.2 @ 1300 nm 0.3 @ 1550 nm	0.3 @ 1300 nm 0.45 @ 1550 nm
C_d	3 pF	1 pF	2 pF
Excess noise factor	$M^{0.3}$	M^{1}	$M^{0.6}$
Bulk dark current	0.10 pA	1 μA	0.1 μA
Surface dark current	0	1 nA	0

IMPORTANT: Specifications of numbered components are shown in the tables.

1. Consider a detector with a quantum efficiency of 50% operating at 1300 nm at a bit rate of 1 Gb/s.

   (a) Find the average power in a data stream required to achieve a BER of 10^{-15} if the performance of the detector is limited only by the quantization of the charge being created by the incoming photons.

   (b) Find the average number of charge carrier pairs that are generated by the arrival of a logical **1**.

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2. A fiber link, operating at 3 Gb/s, uses inline fiber amplifiers designed to keep the total output power after each amplifier constant at a value equal to the link input power, 8 mW. The operating wavelength is 1550 nm. The loss coefficient of the fiber between the amplifiers is 0.6 dB/km. Consider fiber amplifiers with $G_0 = 33$ dB, $LG_0 = 4$, $n_{sp} = 1.2$, and $\Delta\nu = 3$ THz. A filter with a spectral bandwidth of 1.2 nm is inserted in the link immediately after each amplifier.

   (a) Calculate the equivalent bandwidth of the cascaded filters after ninety (90) stages.

   (b) Calculate R_{ASE} after ninety stages.

   (c) Calculate the BER that can be achieved after ninety stages.

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3. A single-mode fiber link, operating at 500 Mb/s at 1550 nm, is desired to have a dispersion-limited distance of 50 km when operating with a source with a spectral width of 1 nm. The coding of the data is nonreturn-to-zero.

   (a) Calculate the maximum total dispersion, D, with units of ps$\cdot$nm$^{-1}\cdot$km^{-1} that is allowed.

   (b) If an 8/125 singlemode fiber is used with a core index of 1.47 and a fractional difference in the index of refraction of 0.45%, calculate the dispersion, D, of this fiber in units of ps$\cdot$nm$^{-1}\cdot$km^{-1}.

   (c) Can this fiber achieve the desired dispersion-limited distance? (Show your reason.)

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4. An optical link has components with the specifications indicated here.

	Min.	Typ.	Max.	Units
Connector loss (per joint)	1	1.5	2	dB
Splice loss (per splice)	0.1	0.15	0.2	dB
Fiber loss	0.6	0.65	0.7	dB/km
Source power (in fiber)	500	600	700	μW
Receiver power (B'_R in Mb/s)	$10\log(B'_R) - 60$	$10\log(B'_R) - 58$	$10\log(B'_R) - 56$	dBm

Find the dynamic range of a link operating at 1300 nm at a bit rate of 500 Mb/s that has a total fiber length of 10 km, 30 splices, and 4 connector joints

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5. Consider the link shown in Figure 1 that uses LED #3 as the source and detector #1 as the receiver. The pigtails on the 4x4 coupler and the receiver are made of fiber #1. The lines connecting the coupler to the sources and receiver are made of fiber #2.

Assuming ideal alignment of each splice, use a power budget analysis to calculate the distance, L, between the transmitter and the star coupler (or between the star coupler and the receiver) if the receiver requires -65 dBm of power to achieve the desired BER. (You may neglect the lengths of all pigtails.)

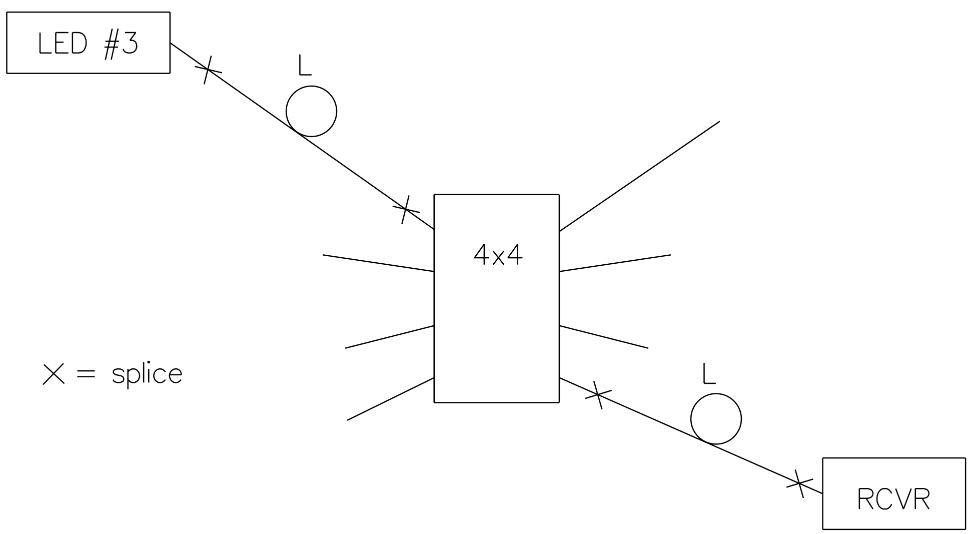

Figure 1: Local area network for Problem 5.