UCL DEPARTMENT OF ELECTRONIC &
ELECTRICAL ENGINEERING

Masters Programmes in Communications

Broadband Technologies and Components

16th November 2018

Closed Book Exam

10.00am - 12.30pm

Guidelines:

- This paper comprises 2 sections:
  Section 1 is **2 compulsory questions** each worth 30%. It is advised that you spend no longer than 1 hour and 30 minutes on this Section.
- **Section 2** contains 3 questions of which you must answer **2 questions only**
- Please **answer each question** in a **separate answer book**
- The distribution of marks among parts of questions is indicated for guidance

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Physical Constants

Velocity of light in a vacuum, $c = 3 \times 10^{8}$ ms^{-1}
Planck's constant, $h = 6.626 \times 10^{-34}$ Js
Boltzmann's Constant, $k = 1.38 \times 10^{-23}$ Joule/Kelvin
Electron Charge, $e = 1.602176 \times 10^{-19}$ C
0°C = 273 K

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Section 1 ***This section has* two *compulsory questions Each is worth 30% of the total mark.***

Please answer each question in a separate answer book.

Optical Design question

Question 1

Determine the different elements (type of fibres and fibre length, number of amplifiers etc…) to build an efficient link operating over 200 km at 10 Gb/s.

Transmitter	DFB laser
Laser Wavelength	1550 nm
Laser Linewidth	100 kHz
Peak transmitter output	10 mW
Fibre:	Standard single mode with
	Dispersion 17 ps/nm.km @ 1550 nm
	Attenuation 0.2 dB/km
	Dispersion compensated fibre
	Dispersion -34 ps/nm.km @ 1550 nm
	Attenuation 0.35 dB/km
Receiver Sensitivity	-27 dBm (BER=10^{-9} at 1550 nm and modulation of 10 Gbit/s)
EDFA:	Saturated power: 16 dBm
	Gain: 30 dB
	Noise Figure: 5 dB

State and justify any assumptions included in your calculations.

[100%]

Question 2

a) State and briefly explain the two types of small-scale fading based on the multipath delay spread.

[30%]

b) Design a microwave line of sight link of range of 5km and a desired data rate of 500 Mbit/s. The link operates on a 2 GHz carrier and you have available two identical antennas with a gain of 6 dBi each, and each fed by a coaxial cable with coupling efficiency of 50%. The receiver front end equipment has a noise figure of 3 dB and is operating at room temperature (27 ^oC). The transmission bandwidth available is limited to 300 MHz.

i. Using appropriate calculations and assuming a double-sided pass-band transmission, choose a modulation scheme from the ones listed in Fig. 1 below, that achieves the target data rate and maximises the energy efficiency of your transmitter.

[35%]

ii. Calculate the transmit power in dBW required for your selected modulation scheme, for data transmission with a maximum error rate of 10^{-6}, and using free-space power budget calculations and Fig. 1 below.

[35%]

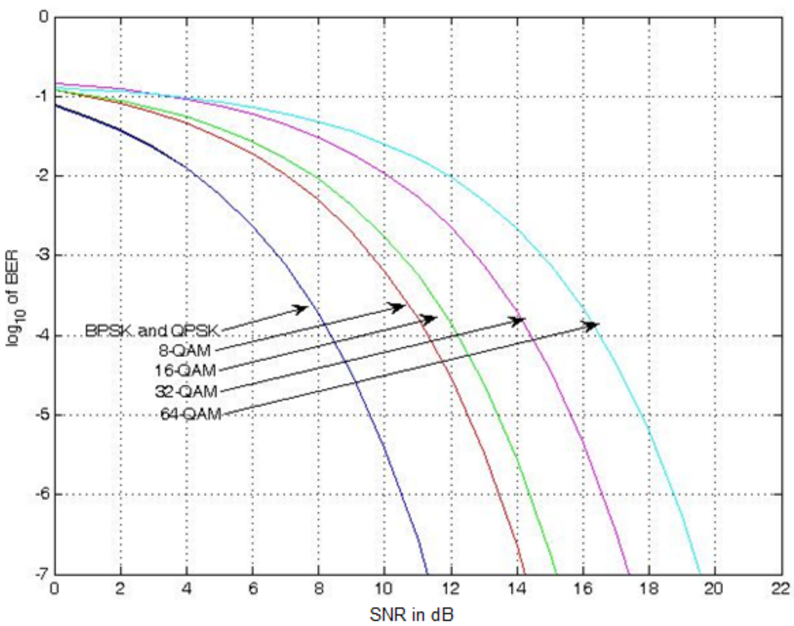

Figure 2.1: Bit Error Rate versus SNR for different modulation schemes

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Section Two

This section contains 3 questions. Answer ***2 questions only.***

Please answer each question in a separate answer book.

Question 3

a) Draw a graph showing the typical gain and bandwidth of an erbium doped optical fibre amplifier, EDFA. Take care to add numerical labels of typical wavelength, bandwidth and gain.

[10%]

b) Briefly list 4 benefits of optical fibre amplifiers as opposed to semiconductor optical amplifiers, SOAs.

[16%]

c) List 4 noise sources which exist in a receiver once an optically amplified signal with Amplified Spontaneous Emission, ASE has been directly detected, and write a mathematical expression for each type of noise in units of photons squared per Hertz OR in units of receiver current.

[16%]

d) State which noise sources are dependent on the amplitude level of the original signal entering the optical amplifier and which noise sources have a much wider bandwidth than the original signal.

[16%]

e) Briefly explain the reason for the differences in the spectral bandwidths of the different types of noise.

[6%]

f) Discuss the benefits of wavelength division multiplexing compared to time division multiplexing, taking care to consider both the optical source and the optical fibre.

[15%]

g) Draw a fully labelled schematic diagram using recognised symbols for an optical wavelength routing add-drop multiplexer.

[18%]

h) How is an original incoming signal affected by passage through an add-drop multiplexer when an additional 10 Gb/s signal at a different wavelength is added?

[3%]

Question 4

a) Discuss the main reasons for the use of raise cosine filtering in an NRZ OOK optical link. Comment on what roll-off factor you would use in that context.

[30%]

b) In a system with equal noise on 1 and 0 and equiprobable 1s and 0s, demonstrate that considering a normally distributed noise we have the probability of error as:

$$P_e \approx \frac{1}{\sqrt{2\pi SNR}} e^{-\frac{SNR^2}{2}}$$

Hint: for a Normal distribution $N(s)$ centred at +A and of widths σ we have

$$\int_{-\infty}^{0} N(s)ds \approx \frac{1}{\sqrt{2\pi}} \sqrt{\frac{\sigma}{A}} e^{-\frac{A^2}{2\sigma^2}}$$

[40%]

c) Using a diagram or otherwise, demonstrate how the Q factor can be determined from an eye diagram.

[30%]

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Question 5

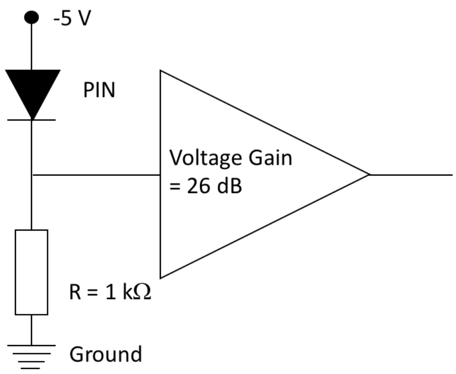
a) Discuss the reasons in terms of output performance and electron behaviour, for biasing a laser well above its threshold point. In your discussion explain stimulated emission of radiation. Plot any graphs you need to help you in your discussion.

[25%]

b) Calculate the cavity length in microns of a semiconductor Fabry-Perot Laser having a wavelength in free space of 1.55 μm, made from a crystalline material with a refractive index of 3.4 if the strongest longitudinal mode has 999 half wavelengths within the cavity. Comment on whether you consider your answer to be reasonable.

[25%]

c) An optical receiver is driven by a 125 Mbit/s input signal of an average optical power of -30 dBm. The receiver is constructed from a pin photodiode with a responsivity of 0.8 A/W and a diode capacitance of 0.6 pF; a 1kΩ load resistor and a 6 GHz amplifier as in the block diagram below:



Knowing that the amplifier has a very large input resistance (> 100 kΩ) and an input capacitance of 0.5 pF, answer the following questions and show the details of how you obtain your answers.:

i- The peak voltage output of the receiver.

[25%]

ii- Would this optical receiver front end require a post-amplification equaliser? Justify your answer by appropriate calculations.

[25%]

END OF PAPER

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