UCL DEPARTMENT OF ELECTRONIC &
ELECTRICAL ENGINEERING

Masters Programmes in Communications

Broadband Technologies and Components

20th November 2015

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 these questions
- **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

---

IGDP Communications for Industry
MSc in Communications Research
MSc in Telecommunications
MSc in Telecommunications with Business
MSc in Internet Engineering
MSc in Wireless and Optical Communications
MRes Photonic Systems Development
EngD in Communications

Physical Constants

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

NEXT PAGE

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

For a link distance of 500 km, derive the details of a full link for 10 Gbit/s considering the following potential elements.

Transmitter	DFB laser
Laser Wavelength	1550 nm
Laser Linewidth	<1 MHz
Peak transmitter output	2 mW
Fibre:	Standard single mode with
	Dispersion 16 ps/nm.km @ 1550 nm
	Attenuation 0.2 dB/km
	Dispersion compensated fibre
	Dispersion -38 ps/nm.km @ 1550 nm
	Attenuation 0.35 dB/km
EDFA:	Saturated power: 16 dBm
	Gain: 30 dB
	Noise Figure: 5 dB
Receiver Sensitivity	-27 dBm (BER=10^{-9} at 1550 nm and modulation of 10 Gbit/s)

State and justify any assumptions included in your calculations.

[100%]

Question 2

a) With the aid of simple mathematical expressions, explain the process of channel estimation based on signal correlation. Based on these expressions, what is the major property of the pilot waveforms that is desired for accurate channel estimation?

[30%]

b) You are asked to design a microwave Line of Sight (LoS) link to transmit a 200 Mbit/s data stream over a distance of 2km, using a 1 GHz carrier with a transmission bandwidth limited to 100 MHz. The link employs two identical microwave transmit and receive antennas, each having a gain of 6 dBi and each fed by a coaxial cable with coupling efficiency of 20%. The receiver and transmitter antennas are at the same height above sea level and the receiver front end equipment has a noise figure of 8 dB and is operating at room temperature (27 ^{o}C). Attenuation due to rain and pollution could be as high as 3 dB/km.

i. Choose an appropriate modulation scheme from the ones included in Fig. 2.1 below, that achieves the target data rate and minimises the required transmission power. You should fully justify your selection by appropriate calculations and clearly state any assumption you make.

[35%]

ii. The target of the link is for a maximum error rate of 10^{-4} in the data transmission. Using free-space power budget calculations and Figure 1 below, determine the transmit power required for your selected modulation scheme

[35%]

NEXT PAGE

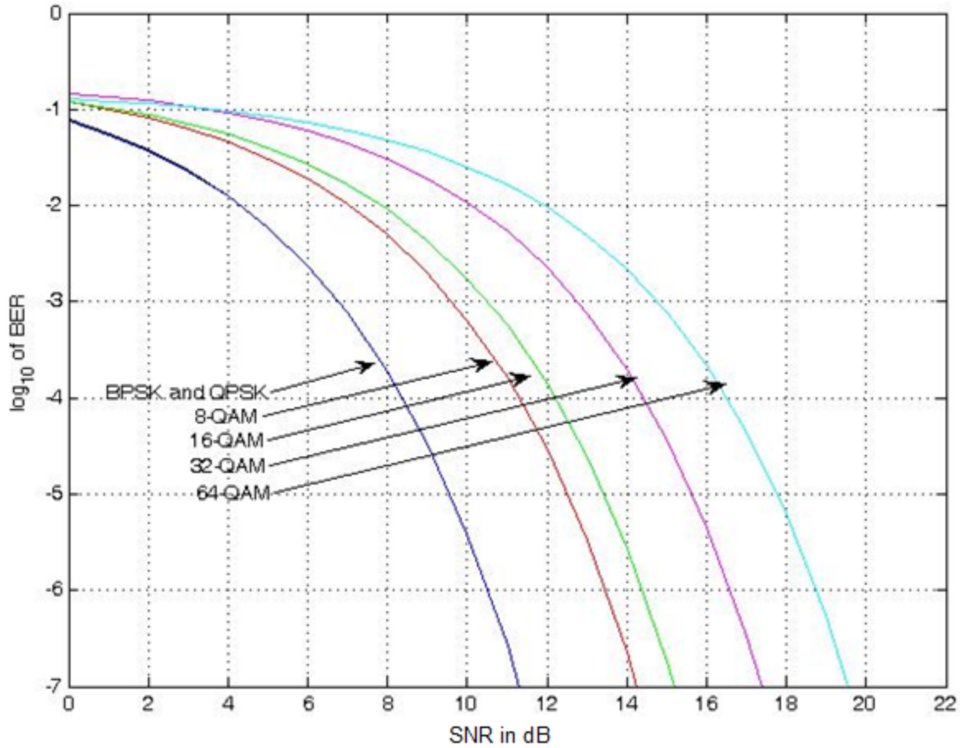

Figure 2.1: Bit Error Rate versus SNR for different modulation schemes

TURN OVER

Section Two

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

Please answer each question in a separate answer book.

Question 3

a) Recommendation ITU-T G.694.2 (2003), "Spectral grids for WDM applications: CWDM wavelength grid" specifies the wavelength grid for coarse wavelength division multiplexing (CWDM) applications. This wavelength grid supports a channel spacing of 20 nm. Calculate the number of wavelength channels that can be supported between and including the wavelengths 1271 nm and 1611 nm.

[15%]

b) Recommendation ITU-T G.694.1 "Spectral grids for WDM applications: DWDM frequency grid" specifies a frequency grid which supports a variety of DWDM channel spacings including 100 GHz, 50 GHz, 25 GHz and 12.5 GHz in frequency units, anchored to 193.1 THz for unidirectional transmission.
For channel spacings of 12.5 GHz on a fibre, the allowed channel frequencies (in THz) are defined by:
$193.1000 + n \times 0.0125$ where n is a positive or negative integer including 0
For channel spacings of 12.5 GHz on a fibre, calculate the wavelengths in nanometres of the 11 channel nearest to, either side of and including the anchor frequency of 193.1000 THz. [15%]

c) Forty 10 Gb/s optical channels spaced by 100 GHz can be supported in C-Band. Calculate the aggregate bit rate along a unidirectional optical fibre channel. [10%]

d) Draw the schematic symbol for a Wavelength Division Demulitiplexer.

[6 %]

e) Draw a detailed schematic of an Arrayed Waveguide Grating, AWG, device. Explain how it works and the purpose of each of the detailed features in it making sure that you also explain the meaning of the word "*waveguide*".

[40%]

f) Explain what precautions need to be taken when an Arrayed Waveguide Grating, AWG, is used. [8%]

g) Sketch the output spectra from an Arrayed Waveguide Grating, AWG. [6%]

Question 4

a) State three different sources of noise in a digital system transmission and explain how they affect the system.

[30%]

b) In a system without amplifier how does the Q factor relate to the SNR?

[20%]

c) State how the Q factor is related to the BER.

[20%]

c) Explain the purpose of a raised cosine filter for NRZ optical signal transmission and its impact on the bandwidth.

[30%]

Question 5

a) Draw a diagram for a typical Mach Zehnder Modulator

[10%]

b) Considering that the phase difference $\Delta\phi$ between the two signals in each arms of the modulator is related to the drive voltage as $\Delta\phi = \alpha \cdot V$ derive the relation between the output power of the modulator and the drive voltage

[40%]

c) Your optical receiver, operating at room temperature of 27° C, is constructed from a pin photodiode with a responsivity of 0.8 A/W, and a 200Ω load resistor R, followed by a 12 GHz amplifier as in Figure 5.1:

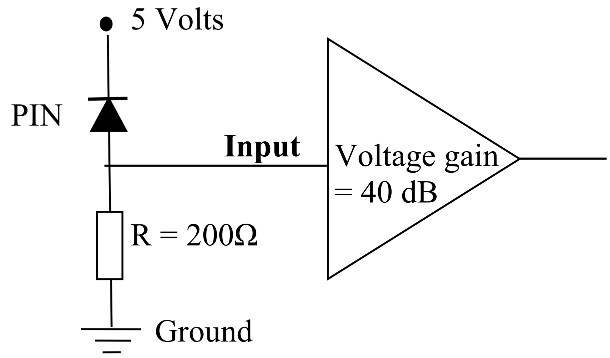

Figure 5.1: Schematic of the receiver circuit

The input to the receiver is an equi-probable 10 Gbit/s optical binary signal. Derive the rms input noise current at the input of the receiver and the corresponding receiver sensitivity (in dBm) for operating at a BER of 10^{-9} ,knowing that the required Q factor for BER of 10^{-9} is equal to 6.

[50%]

END OF PAPER