ES4C40

THE UNIVERSITY OF WARWICK

Fourth Year/MSc Examinations: Summer 2023

OPTICAL COMMUNICATION SYSTEMS

Candidates should answer ALL FOUR QUESTIONS.

Time Allowed: 2 hours.

Only calculators that conform to the list of models approved by the School of Engineering may be used in this examination. The Engineering Databook and standard graph paper will be provided.

Read carefully the instructions on the answer book and make sure that the particulars required are entered on each answer book.

1.

Figure 1.1 shows a schematic of a simple optical fibre transmission system using on-off keying.

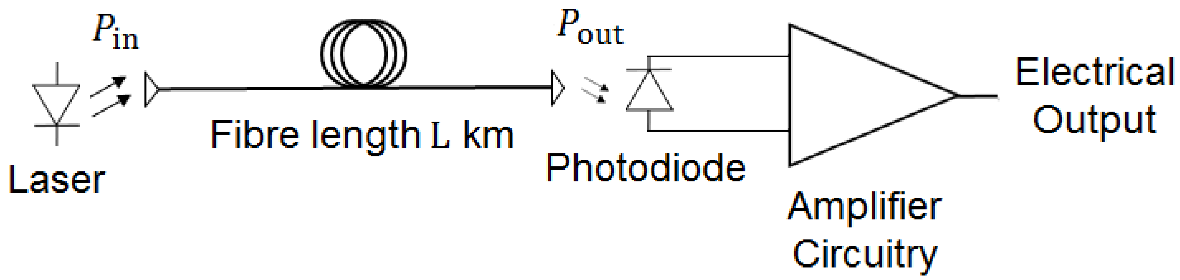

Figure 1.1

(a) Determine the number of photons arriving per second when $P_{\text{out}} = 200\ \text{nW}$ at a wavelength of 1550 nm. State whether the number of photons per second would be larger or smaller for a shorter wavelength and why.

(3 marks)

(b) Further to part (a), the laser in Figure 1.1 delivers $P_{\text{in}} = 5\ \text{mW}$ into the fibre with negligible coupling loss. Calculate the propagation loss in dB per km when $L = 200\ \text{km}$.

(3 marks)

(c) The photodiode in Figure 1.1 has a quantum efficiency of 0.6. Show that the mean photocurrent that results from P_{out} in part (a) is 150 nA at a wavelength of 1550 nm.

(3 marks)

(d) Show that the bit error rate (BER) of the system in Figure 1.1 at a temperature of 300 K for the photocurrent in part (c) when thermal noise dominates the receiver is approximately 10^{-9}. The receiver has a noise equivalent bandwidth of 755 MHz, an effective load resistance of 100 kΩ and includes an amplifier with a noise figure of 7 dB.

(8 marks)

Question 1 continued overleaf ...

Question 1 continued...

(e) The bit rate of the system in Figure 1.1 is 622 Mbps. Calculate the average time between errors and comment on the result.

(2 marks)

(f) The fibre in Figure 1.1 is upgraded to one that has a loss of 0.15 dB per km and a new 1550nm wavelength laser is also used. Find the laser power needed to improve the bit error rate by three orders of magnitude when the receiver properties are unchanged. The SNR required for a given BER may be approximated by the expression:

$$SNR \approx -18\log_{10} BER - 17.4$$

(6 marks)

(Total 25 Marks)

Continued ...

2.

(a) Outline with the aid of a diagram, the purpose, structure and operation of a 2x2 fused biconical tapered optical fibre coupler.

(6 marks)

(b) An optical field E_i is launched into the upper input arm of an ideal 2x2 fused biconical tapered optical fibre coupler, producing outputs E_1 and E_2 from the upper and lower output arms respectively. This process may be represented using a transfer matrix $\boldsymbol{T}$ for the coupler thus:

$$\begin{pmatrix} E_1 \\ E_2 \end{pmatrix} = \boldsymbol{T} \begin{pmatrix} E_i \\ 0 \end{pmatrix}.$$

Explain, with appropriate mathematical content, why $\boldsymbol{T}$ can be represented as shown below, when the fraction of the power transferred to the bottom arm is ρ.

$$\boldsymbol{T} = \begin{pmatrix} \sqrt{1-\rho} & j\sqrt{\rho} \\ j\sqrt{\rho} & \sqrt{1-\rho} \end{pmatrix}$$

(6 marks)

(c) Figure 2.1 shows part of the absorption coefficient characteristics of a compound semiconductor at zero bias and subject to an applied electric field. Estimate the insertion loss of a 50 µm long electroabsorption waveguide modulator fabricated from this material operating at a wavelength of 1.32 µm.

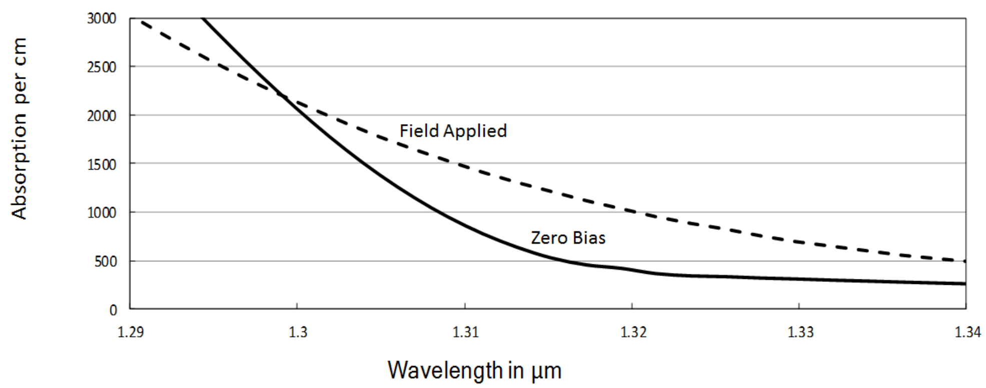

Figure 2.1

(4 marks)

Question 2 continued overleaf ...

Question 2 continued …

(d) The modulator considered in part (c) is used with a 1 mW, 1.32 μm wavelength laser to produce non-return to zero pulses that are fed into one input of an 8x8 coupler comprised of ideal 2x2 fused biconical tapered optical fibre couplers with $\rho = 0.5$. Determine the power in dBm received in the “on” and “off” states at one of the outputs of the coupler, ignoring any excess losses.

(7 marks)

(e) What is the extinction ratio of the system in part (d)?

(2 marks)

(Total 25 Marks)

3.

(a) An optical fibre communication system is operated at 15 Gbps using a laser with a spectral linewidth of $\Delta\lambda$ = 0.01 nm at a central wavelength of 1550 nm. The optical fibre has a chromatic dispersion coefficient of D = 16 ps $(nm \cdot km)^{-1}$, a core refractive index of 1.5, a cladding refractive index of 1.48 and a core diameter of 4 µm.

(i) Calculate the number of modes that the optical fibre can support.

(4 marks)

(ii) Calculate the pulse spread per unit distance (ps km^{-1}).

(4 marks)

(iii) What is the frequency spread of the laser in terms of GHz?

(4 marks)

(iv) What is the maximum length of fibre that allows the stated system bit rate?

(5 marks)

(b) What is the required 3-dB optical bandwidth when the communication system in (a) is transmitting a non-return-to-zero (NRZ) signal?

(2 marks)

(c) Determine whether the optical fibre communication system in (a) will operate correctly at 2.0 Gbps employing an NRZ signal when the laser has a 1550 nm central wavelength with a spectral linewidth of $\Delta\lambda$ = 0.2 nm, and the fibre is of length 120 km with a chromatic dispersion coefficient of D = 25 ps $(nm \cdot km)^{-1}$.

(6 marks)

(Total 25 Marks)

Continued ...

4.

(a) Explain the basic principle of light emission in an LED based on the energy band diagram and indicate the nature of the light emission process. Indicate how this light emission process differs from that used in a laser diode.

(8 marks)

(b) Optical wireless communication is a particular form of optical communications. State the relative strengths and weaknesses of optical wireless communication compared to optical fibre communications, and also compare it with conventional radio frequency (RF) communications.

(8 marks)

(c) A set of signals is transmitted over an optical link of 100 km with a fibre loss of 0.3 dB km^{-1}. The link has 4 splices with 0.25 dB loss per splice and 2 connectors with 0.2 dB loss per connector. The receiver sensitivity is 5 μW. Find the minimum transmitter power and express it in both mW and dBm.

(9 marks)

(Total 25 Marks)

END OF PAPER