ES4C40

THE UNIVERSITY OF WARWICK

Fourth Year/MSc Examinations: Summer 2018

OPTICAL COMMUNICATION SYSTEMS

Candidates should answer all FOUR questions.

Time Allowed: 3 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.

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1. A certain bit error rate (BER) tester can reliably measure BER values between 10^{-2} and 10^{-10}. It is used to characterise a 1 Gbps transmission link by taking back-to-back measurements and then measurements over distances of 20 km and 50 km. The resultant BER values are shown in Table 1 below.

Table 1

Received Power (dBm)	Back-to-back	20 km	50 km
-24.5	7.6×10^{-5}	2.0×10^{-3}	-
-24.0	2.9×10^{-6}	7.8×10^{-5}	-
-23.5	1.1×10^{-7}	3.0×10^{-6}	-
-23.0	4.0×10^{-9}	1.0×10^{-7}	-
-22.5	1.6×10^{-10}	4.2×10^{-9}	3.3×10^{-3}
-22.0	-	1.6×10^{-10}	1.0×10^{-5}
-21.5	-	-	5.0×10^{-7}
-21.0	-	-	3.0×10^{-8}
-20.5	-	-	2.5×10^{-9}
-20.0	-	-	2.9×10^{-10}

(a) Plot the data in Table 1 on a suitable graph and hence estimate the 10^{-9} sensitivities for the three scenarios tested. *(10 marks)*

(b) Discuss the most likely reasons for the worsening performance with distance, distinguishing between the two fibre lengths in terms of power penalty and their different BER curve shapes. *(6 marks)*

(c) Estimate the total connector losses when the transmitter laser power to obtain the 10^{-9} back-to-back sensitivity result is 8 μW. *(2 marks)*

(d) Determine the fibre attenuation per km from the 10^{-9} BER by using the sensitivity results for back-to-back and 20 km transmission. *(3 marks)*

(e) Find the dispersion penalty when the fibre length is 50 km. *(4 marks)*

Total 25 Marks

2. (a) Explain what is meant by intensity modulation in optical communications, distinguishing between direct and external modulation, and indicating why the latter is often necessary in high performance optical transmission systems. *(5 marks)*

(b) Show that the currents resulting from a received '1' and a received '0' respectively in an on-off keyed transmission system are: $I_1 = 2\bar{I}r/(r+1)$ and $I_1 = 2\bar{I}/(r+1)$, where $\bar{I}$ is the mean receiver current and r is the extinction ratio of the modulator.

(6 marks)

(c) Outline with the aid of a diagram the operating principle of a Lithium Niobate Mach-Zehnder optical modulator. *(4 marks)*

(d) Figure 2d below shows the fraction of light transmitted by an optical modulator as a function of its applied bias. Explain why this is most likely the characteristic of an electroabsorption device rather than a Mach-Zehnder modulator. *(2 marks)*

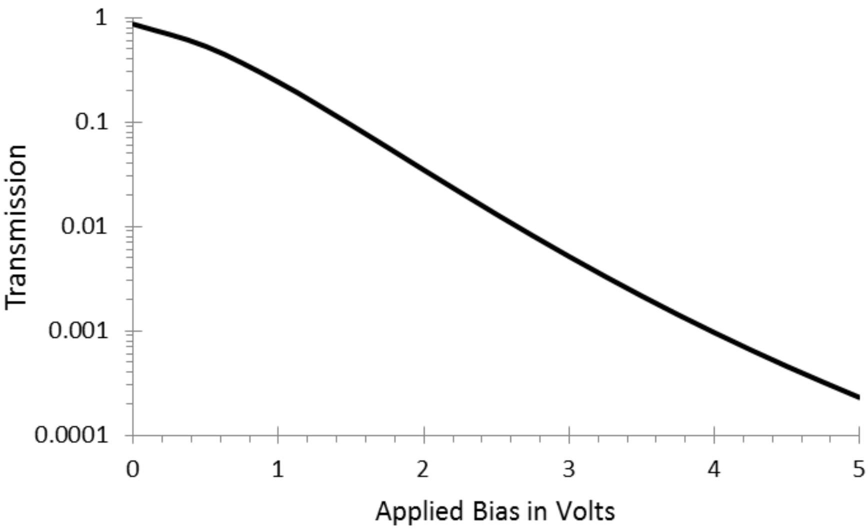

Figure 2d

(e) Estimate the extinction ratio of the modulator in part (d). *(4 marks)*

(f) Estimate the extinction ratio of a modulator device that is half of the length of the one in part (d) but otherwise nominally identical. *(4 marks)*

Total 25 Marks

CONTINUED

3. (a) Design a single-mode optical fibre by specifying the V parameter, and explain the definition and the physical significance of this parameter. *(4 marks)*

(b) A Gaussian optical pulse with a central wavelength of 1550 nm propagates in a single mode optical fibre. At the start of the fibre, the pulse has a $1/e$ pulse width of $T_0 = 10$ ps. The dispersion coefficient of the fibre is $D = 17$ ps nm^{-1} km^{-1}.

(i) Calculate the group velocity dispersion (GVD) parameter $\beta_2 = -D \cdot \frac{\lambda^2}{2\pi c}$, and the dispersion length $L_D = T_0^2/|\beta_2|$. *(4 marks)*

(ii) Ignoring the fibre nonlinearity, the Gaussian pulse in part (i) will be broadened due to fibre dispersion. Calculate the pulse width at distance L_D and also the distance at which the pulse will double its width due to dispersion. *(5 marks)*

(c) The Gaussian optical pulse in part (b) has a peak power of $P_o = 1$ W and travels along an optical fibre having an effective core area of $A_e = 50$ μm^2. The Kerr effect means that the refractive index of fibre core is related to the optical intensity by the expression $n = n_{\mathrm{L}} + n_{\mathrm{NL}} I$, where $n_{\mathrm{L}}$is the linear part of the refractive index, $n_{\mathrm{NL}} = 3 \times 10^{-8}$μm^2 W^{-1} is the nonlinear-index coefficient, I is the optical intensity (cross-sectional power density) of the light in of W per μm^2.

(i) Calculate the maximum refractive index change at the peak of the pulse. *(4 marks)*

(ii) Determine the nonlinear length, $L_{NL} = \frac{\lambda A_e}{2\pi n_{NL} P_0}$, of this pulse in the fibre. *(4 marks)*

(iii) When considering both dispersion and nonlinearity, will the pulse at distance L_D be wider or narrower compared to the values calculated in (b)(ii)? Explain the reason. *(4 marks)*

Total 25 Marks

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4. (a) Explain with the aid of diagram, the basic structure of an optical wireless communication system. Give an example circuit of an optical transmitter which is suitable for optical wireless transmission. *(8 marks)*

(b) Describe the principle of statistical time division multiplexing (STDM) and explain its advantage compared to a conventional time division multiplexing (TDM) technique when bursty traffic is being transmitted. Use appropriate diagrams for the explanation. *(8 marks)*

(c) The bidirectional passive optical network (PON) shown in Figure 4c has a number of subscribers connected to it via a 1×64 star coupler with an excess loss of 5 dB. The central optical line terminal (OLT) is located 10 km from the coupler, and the subscriber optical network terminals (ONTs) between 1 and 10 km from it. All fibres used are standard single mode fibre (SMF) with dispersion of 17 ps nm^{-1} km^{-1} at 1550 nm and zero dispersion at 1310 nm. The network uses 1310 nm for its uplink (ONT to OLT) and 1550nm for its downlink (OLT to ONT). The fibre attenuation at 1310 nm is 0.5 dB km^{-1} and at 1550 nm it is 0.2 dB km^{-1}. The receiver sensitivity at all the ONTs is –35 dBm, and the receiver sensitivity at the OLT is –38 dBm.

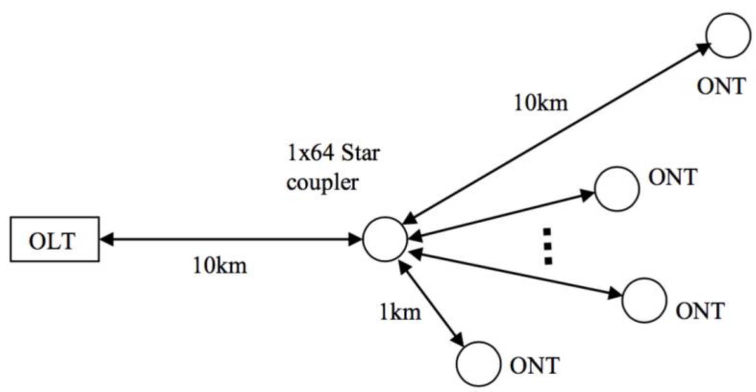

Figure 2

Design such a PON by calculating:

(i) The required minimum transmission power at the OLT. *(4 marks)*

(ii) The required minimum transmission power at the farthest ONT. *(5 marks)*

Total 25 Marks

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