ES4C40

THE UNIVERSITY OF WARWICK

Fourth Year/MSc Examinations: Summer 2019

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) An optical receiver employs a front end consisting of a photodiode with a 1 kΩ load resistor. Calculate the mean squared thermal (Johnson) receiver noise current at 300K when its bandwidth is 200 MHz.

(4 marks)

(b) Find the signal to noise ratio of the receiver in part (a) when a photodiode with responsivity 0.8 AW^{-1} is used and the received power is 250 nW.

(4 marks)

(c) Complete the design of a thermal noise dominated transmission system with an ideal extinction ratio by finding the minimum average signal power in dBm needed to achieve a 10^{-9} bit error rate ($Q \geq 6$) at 300K using the receiver in part (b).

(6 marks)

(d) Explain what is meant by a power budget for an optical fibre transmission system.

(2 marks)

(e) Determine the fibre loss in dB per km when half of the power launched into 10 km of optical fibre arrives at the receiver.

(2 marks)

(f) Form the power budget for the system described in Table 1 below, which utilises fibre and a receiver of the same types as those employed in the calculations previously. Hence calculate the maximum transmission distance for the system when using an input power of 1 mW to achieve at bit error rate (BER) of 10^{-9}.

(7 marks)

Table 1

Fibre loss per kilometre	As determined in part (e)
Connector loss (per connector)	0.5 dB
Mean squared receiver thermal noise (dominant noise source)	As determined in part (a)
Receiver photodiode responsivity	0.8 AW^{-1}
System margin	3 dB

Total 25 Marks

2. (a) Briefly describe, with the aid of a diagram, the operation of a *pn* photodiode, indicating the advantage of using a *pin* structure instead.

(7 marks)

(b) Define the quantum efficiency η of a photodiode. Show that the photocurrent, I_{p}, from a photodiode illuminated with light of power P_0 is given by:

$$I_{\mathrm{p}} = \frac{\eta q}{hf} P_o$$

where q is the electronic charge, h is Planck's constant, and f is the frequency of the light.

(4 marks)

(c) A *pn* photodiode is illuminated from its *p* side, has front face reflectivity of R_{f} and absorption coefficient α (assumed independent of material doping). Show that, when x_1 represents the start of the depletion region and x_2 its end, the diode's quantum efficiency η is given by the formula below, and comment on the implications for photodiode design.

$$\eta = (1 - R_{\mathrm{f}}).\exp(-\alpha x_1).\{1 - \exp(-\alpha[x_2 - x_1])\}$$

(8 marks)

(d) Assuming that the p and n depletion regions are negligibly small, estimate the photocurrent produced by 1μW of optical power at 633 nm and 850 nm illuminating a silicon *pin* photodiode with the following characteristics: top layer thickness 0.5 μm; intrinsic layer thickness 10 μm; top face reflectivity of 30%. The optical absorption coefficient of silicon, α, over this wavelength range may be approximated by the equation:

$$\alpha = 6.9 \times 10^7 \times \exp\left(-\frac{\lambda}{130}\right) \mathrm{~m}^{-1}$$

where λ is in nanometres, and the change in reflectivity between the two wavelengths above may be assumed to be negligible.

(6 marks)

Total 25 Marks

3. (a) Draw a block diagrams of the ring and star topologies that may be used to connect and eight station optical fibre network. Briefly describe with the aid of suitable diagrams how each node in the ring and the star networks may be implemented.

(6 marks)

(b) Explain the term passive optical network (PON) by describing with the aid of diagrams the terms optical line termination (OLT), optical network unit (ONU) and network termination (NT), and indicating the network locations of these elements.

(6 marks)

(c) Explain with the aid of a diagram the implementation of an 8×8 star coupler using 2×2 directional couplers and determine the output power at any of the coupler ports when the input power is -20 dBm and the 2×2 couplers are nominally identical.

(6 marks)

(d) The ITU grid defines the channel spacing in WDM optical systems and networks. At a central wavelength of 1550 nm, the channel spacing can be set to be 50 GHz. Calculate the corresponding channel spacings in terms of their wavelength difference.

(4 marks)

(e) Describe how to achieve a 25 GHz channel spacing from two sets of WDM signals each with 50 GHz channel spacing.

(3 marks)

Total 25 Marks

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4. (a) Fibre dispersion is a major cause of impairment in optical transmission.

(i) Single-mode fibres (SMFs) ($D = 16$ ps nm $^{-1}$km^{-1}) and dispersion compensating fibres (DCFs) ($D = -85$ ps nm $^{-1}$km^{-1}) are used to form a link of 1200 km. Calculate the length of each type of fibre to produce exact zero dispersion. *(5 marks)*

(ii) In a span compensation scheme, the span length contains the correct proportion of SMF and DCF so the span dispersion is zero. Assuming that the span length is 80 km, design a fibre link for a span compensation scheme for the 1200 km link. *(3 marks)*

(iii) In a mid-span compensation scheme, the DCF is concentrated in the middle of the entire link. Design a mid-span compensation scheme for the 1200 km link. *(3 marks)*

(b) A sufficiently powerful optical data pulse with a wavelength of 1550 nm propagates through an optical fibre. The self-phase modulation (SPM) in the optical fibre causes a positive chirp in the pulse. However, its effect on pulse propagation depends on the type of fibre used.

(i) What happens to the pulse when the fibre used is SMF with a dispersion of $D = 16$ ps nm $^{-1}$km^{-1}? *(3 marks)*

(ii) What happens to the pulse when the fibre used is non-zero dispersion shifted fibre (DSF) with a dispersion of $D = -4$ ps nm $^{-1}$km^{-1}? *(3 marks)*

(c) Assuming a single-mode step-index fibre has a core diameter of 3.6 μm and a core refractive index of 1.48, calculate the shortest wavelength which could still permit single mode operation when its relative refractive index difference, Δ, is 0.5%. *(8 marks)*

Total 25 Marks

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