THE UNIVERSITY OF WARWICK

MSc Examinations: Summer 2017

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) A simple optical receiver employs a high impedance front end consisting of a photodiode with a 220 Ω load resistor. Calculate the mean squared thermal (Johnson) receiver noise current at 300K when its bandwidth is 20 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 200 nW.

(4 marks)

c) Complete the design of a thermal noise dominated transmission system with an ideal extinction ratio by determining 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) An optical fibre transmission system is to transmit 1 Gbps on-off keyed (OOK) data channels and operate in the small wavelength region from 820 nm to 821 nm. Find the absolute maximum number of wavelength division multiplexed (WDM) channels that can be sent along the fibre.

(4 marks)

e) The system in part (d) uses Fabry-Perot (FP) filters to select its channels, which may be approximated by a low pass filter characteristic. Estimate the number of channels that can be accommodated with a 3 dB mean crosstalk power penalty using FP filters whose full-width at half-maximum is 0.02 nm.

(7 marks)

Total 25 Marks

CONTINUED

2. a) Explain what is meant by coherent optical communications and why this form of optical system has become the subject of renewed research and development interest in recent years.

(5 marks)

b) Define the terms "homodyne" and "heterodyne" in the context of coherent optical receivers.

(2 marks)

c) Considering a homodyne amplitude shift keyed (ASK) coherent receiver with a powerful local oscillator, show that the received photocurrent (I_{COH}) is given in terms of the receiver photodiode responsivity, R, the received power, P_s, and the local oscillator power, P_L, by the expression:

$$I_{\mathrm{COH}} \approx 2R\sqrt{P_{\mathrm{S}}}\sqrt{P_{\mathrm{L}}}$$

(8 marks)

d) Show further that using a high powered local oscillator, the signal to noise ratio (SNR) of the receiver is:

$$SNR \approx \frac{2RP_s}{q\Delta f}$$

where q is the electronic charge and Δf is the receiver bandwidth.

(5 marks)

e) Hence estimate the SNR advantage in dB of the coherent homodyne ASK receiver over an ideal thermal noise dominated direct detection 50 Ω load receiver when the received power is −30 dBm at a wavelength of 1550 nm and a temperature of 300K.

(5 marks)

Total 25 Marks

CONTINUED

3. a) Outline the basic principle of operation of a step index optical fibre using the ray-based approach.

(5 marks)

b) Explain what is meant by the numerical aperture (NA) of a step index fibre and obtain an expression for the NA.

(5 marks)

c) Calculate the numerical aperture of a step index fibre, given that the free space refractive index is $n_0 = 1.00$, the refractive index of the core of the step index fibre is $n_1 = 1.5$, and the refractive index of its cladding is $n_2 = 1.492$.

(2 marks)

d) Design a fibre with the physical properties in part c) to have the maximum core radius to be single mode at a wavelength of 1300 nm.

(3 marks)

e) Show using the Gaussian approximation to the fundamental mode of the fibre that the ratio of the power in the core to total power in the fibre is given in terms of its spot size, ω_0, and its core radius, a, by:

$$\frac{P_{core}}{P_{total}} = 1 - \exp\left(-\frac{2a^2}{\omega_0^2}\right)$$

(7 marks)

f) Determine the fraction of the power travelling in the core when the fibre in part d) has the maximum core radius for single mode operation and operates at 1300 nm, assuming that the approximation $\omega_0/a \approx \left(\sqrt{\ln V}\right)^{-1}$ in terms of the fibre *V* parameter applies.

(3 marks)

Total 25 Marks

CONTINUED

4. a) Describe with the aid of a diagram what is meant by Radio over Fibre (RoF) and the rationale for its employment in future mobile communication systems.

(5 marks)

b) Figure 1 shows a symbolic representation of part of a RoF system. Explain the abbreviations, "L", "PD", "PA" and "LNA" used in the figure.

(2 marks)

c) The upstream and downstream fibre links in Figure 1 are nominally identical and consist of 10 km of fibre (loss 0.2 dB km^{-1}; adds no noise), a transmitter (loss 20 dB; noise figure 20 dB) and a receiver (gain 10 dB; noise figure 10 dB). Determine the overall loss and noise figure that apply to both of the fibre links.

(8 marks)

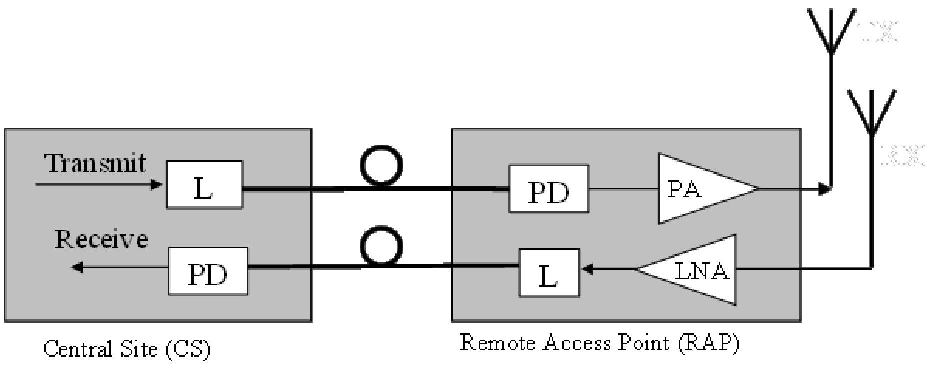

Figure 1

d) The LNA has a gain of 25 dB and noise figure of 3 dB, whereas the PA has a gain of 40 dB but a noise figure of 7 dB. Determine the uplink signal to noise ratio (SNR) at the CS when the SNR is 20 dB prior to the LNA and the downlink SNR at the Remote Access Point given an SNR of 40 dB at the central site transmitter.

(10 marks)

Total 25 Marks

END