THE UNIVERSITY OF ADELAIDE
AUSTRALIA

EXAMINATION FOR THE DEGREE OF B.E. and M.E.

Semester 2 2006

101908 OPTICAL COMMUNICATION ENGINEERING (ELEC ENG 4041)
101942 PHOTONICS FOR COMMUNICATION (ELEC ENG 7045)

Official Reading Time: 10 mins
Writing Time: 120 mins
Total Duration: 130 mins

Instructions:

- This is a closed book examination.
- Attempt **ALL** FOUR questions.
- All questions carry equal marks; part marks are given in brackets where appropriate.
- Begin each answer on a new page.
- Examination materials must not be removed from the examination room.
- **ANSWERS TO QUESTIONS SHOULD BE EXPRESSED CLEARLY AND WRITTEN LEGIBLY. THESE ASPECTS OF PRESENTATION WILL BE TAKEN INTO ACCOUNT IN ASSESSMENT.**

Materials:

- The use of calculators is permitted, this equipment to be supplied by the candidate. No pre-recorded material nor calculator instruction book is permitted, and calculators with remote communication links will be barred from the examination room.
- Formulae sheets (3 pages) are attached at the end of the paper.

DO NOT COMMENCE WRITING UNTIL INSTRUCTED TO DO SO.

Question 1 begins on page 2

1. Consider a single mode fibre operating at 1550 nm. The specification is to transmit 400 Mbps NRZ data over the 100 km fibre link with a bit error rate (BER) of 10^{-9} or better.

(a) Given that $\tau = 1/R_{NRZ}$ and allowing for the system rise time to be 70% of τ, compute the system rise time t_S.

(1 mark)

(b) Given a material dispersion of M = -20 ps/nm/km and a waveguide dispersion of M_g = 4.5 ps/nm/km, compute the fibre rise time, t_F. The spectral linewidth is given as 0.15 nm.

(1 mark)

(c) If the rise time of the light source is $t_{LS} = 1\,\text{ns}$, find an upper limit on the photodetector rise time t_{PD}.

(4 marks)

(d) Assume a basic BJT amplifier circuit at the receiver. If the photodetector has a transit time limited rise time of $t_{TR} = 0.5\,\text{ns}$ and a junction capacitance of $C_d = 1\,\text{pF}$, calculate an upper limit on the load resistor.

(2 marks)

(e) Given that the fibre loss is 0.25 dB/km, the coupling efficiency to the fibre is 3 dB, there are two connectors with 1 dB loss each, there are 50 splices with 0.1 dB loss each and that the source power is 5 dBm, find the power at the receiver.

(2 marks)

(f) Calculate the optical power needed to achieve the specified BER assuming a quantum limited system. Comment on the result. You may assume dark current is negligible and therefore the expression for probability of an error $P_e = e^{-n_s}$ holds. The quantum efficiency of the detector is η = 0.7.

(4 marks)

(g) Now calculate the optical power needed to achieve the specified BER assuming a thermal limited system. Comment on the result. You may assume a detector responsivity of ρ = 1 A/W and a noise figure of F = 2. Room temperature conditions hold, thus let T = 300 K.

(6 marks)
(Total marks 20)

You are reminded to clearly highlight your answers with a double underline, otherwise marks may be deducted.

2 (a) The power incident on a detector of light is 100 nW.

(i) Determine the number of photons per second incident on the detector if the wavelength is 800 nm (1.5 mark)

(ii) If we carried out the above calculation for a longer wavelength, briefly state if the number of photons per second goes up or down, and why? (1 mark)

(b) A T3 system running at 45 Mbps has a BER of 10^{-9}, compute the number of errors per minute. (0.5 mark)

(c) To operate properly, a particular fibre optic receiver requires -34 dBm of power. The system losses are 31 dB in total, from the light source to the receiver. Compute the power in mW that the light source needs to emit to meet the requirement. (2 marks)

(d) A cable contains 144 single-mode fibres, each operating at 2.3 Gb/s. How many digitised 64 kbps voice messages can be transmitted along this cable? (1 mark)

(e) What is the difference (in Watts) between -65 dBm and 65 dBm? (1 mark)

(f) A fibre system operates with a carrier wavelength of 1.55 μm. Suppose that the system can handle digital information at a rate equal to one-hundredth of one percent of the optical frequency. How many 20 Mbps HDTV compressed video channels can be multiplexed onto this fibre system? (2 marks)

(g) Prove that the power change γ in dB/km and the attenuation coefficient α are related by $\gamma = -8.685\alpha$, where α is given in the units of km^{-1}. (3 marks)

(h) Derive the dynamic range of a conventional compact disc (CD) in dB. (2 marks)

(i) A CD has several levels of error detection and correction. Provide a very brief description of the following, and explain their purpose:

(i)	Eight to Fourteen Modulation (EFM)	(2 marks)
(ii)	Reed-Solomon Code	(2 marks)
(iii)	Interleaving	(2 marks)

(Total marks 20)

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3. Consider a heterodyne receiver for a digital optical fibre communications system.

   (a) Briefly explain how a heterodyne receiver detects *phase*, given that photodetectors can only detect amplitude or optical power. (2 marks)

   (b) State the key advantage of phase detection over amplitude detection. (1 mark)

   (c) What type of optical modulation scheme can a heterodyne system permit that is not otherwise achievable with direct detection using a standard receiver? (1 mark)

   (d) Heterodyne receivers offer increased sensitivity. Briefly state why. (1 mark)

   (e) Using a heterodyne receiver, compute the local-oscillator (LO) power required to make the SNR 1 dB *less* than the quantum limit. You may assume the IF bandwidth is 500 MHz and the received optic power is constant at 5 nW when a binary "1" is received. The dark current of the photodetector is I_D = 5 nA, and its responsivity is ρ = 0.4 A/W. Assume the temperature is 27°C and a load resistance of 100 Ω. (11 marks)

   (f) If this were *not* a heterodyne system, then the receiver's bandwidth could be as small as 250 MHz in the case of a direct detection system. For this case determine the signal power required to achieve a SNR equal to that in part (e). (4 marks)

   (Total marks 20)

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4. (a) A laser diode has a RIN of -135 dB/Hz. A receiver bandwidth of 1 GHz and a received average power of 20 μW.

   (i) Compute the laser noise power at the receiver. (1 mark)

   (ii) Compute the average laser noise current if the detector has a responsivity of 0.3 A/W. (1 mark)

(b) Prove Johnson's thermal noise formula $\langle e_n^2 \rangle = 4kTR\Delta f$, where the symbols have all their usual meanings, by taking the following steps:

(i) Consider a resistor in parallel with a capacitor. Draw the equivalent circuit assuming the noisy resistor can be modelled by a single source in series with a lumped ideal resistor. Label the source $\langle e_n^2 \rangle$. Label the mean square noise across the capacitor. Label the source $\langle v_n^2 \rangle$. Label the mean square noise current through the loop $\langle i_n^2 \rangle$. The angle brackets represent temporal averages.

(1 mark)

(ii) Apply Kirchhoff's voltage law (KVL) around the loop, and write down the equation in terms of time limited variables $e_n(t,\tau)$, $v_n(t,\tau)$ and $i_n(t,\tau)$, assuming that we sample these random signals for a finite time window of duration τ. Here we assume the window is sufficiently long and that stationarity holds. Briefly explain what stationarity means.

(2 marks)

(iii) Assuming this equation is free of delta functions, now write down the same equation in terms of window-limited Fourier transformed variables, $V_n(\omega,\tau)$ and $I_n(\omega,\tau)$.

(1 mark)

(iv) By substituting in the relation $I_n(\omega,\tau) = j\omega C V_n(\omega,\tau)$ and then applying Plancherel's theorem (i.e. the energy theorem), prove that,

$$\langle e_n^2 \rangle = \lim_{\tau\to\infty} \frac{1}{2\pi} \int_0^{+\infty} 2\frac{|E_n(\omega,\tau)|^2}{\tau} d\omega .$$

(6 marks)

(v) Explain why we cannot take the limit inside the integral without first taking ensemble averages. Now, by assuming the system is ergodic, i.e. $\lim_{\tau\to\infty} \langle e_n^2 \rangle_\tau = \overline{e_n^2}$, where the overbar indicates ensemble averaging, show that,

$$\langle e_n^2 \rangle = \frac{1}{2\pi} \int_0^{+\infty} S(\omega) d\omega$$

where $S(\omega)$ is the one-sided power spectral density (PSD).

(3 marks)

(vi) Explain why for thermal noise, we can simply rewrite this expression as $\langle e_n^2 \rangle = \frac{1}{2\pi} S_0 \Delta\omega$, where S_0 is a constant PSD.

(1 mark)

(vii) By identical arguments to part (v), we can write down a similar expression for the mean square noise voltage across the capacitor as

$$\langle v_n^2 \rangle = \frac{1}{2\pi} \int_0^{+\infty} \lim_{\tau \to \infty} \frac{2\overline{V_n^2}}{\tau} d\omega .$$

Now, substitute this into $|V_n|^2 = \frac{|E_n|^2}{1+(\omega RC)^2}$, and then show that

$$\langle v_n^2 \rangle = \frac{1}{2\pi} S_0 \frac{\pi}{2RC} .$$

(2 marks)

(viii) From the equipartition theorem you may assume that $\frac{1}{2} C \langle v_n^2 \rangle = \frac{1}{2} kT$. Use this relation to now finally arrive at the thermal noise formula.

(2 marks)
(Total marks 20)

You are reminded to clearly highlight your answers with a double underline, otherwise marks may be deducted.

END OF EXAMINATION QUESTIONS