THE UNIVERSITY OF ADELAIDE
AUSTRALIA

EXAMINATION FOR THE DEGREE OF B.E. and Eng. Masters

Semester 2 2005

4041 OPTICAL COMMUNICATION ENGINEERING
7045 PHOTONICS FOR COMMUNICATION

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:

- One Pink Book
- 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 (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)

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)

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

2. 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 27ºC 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)

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

3.
(a) A long fibre, of arbitrary length, has 10 optical amplifiers equally spaced along its length. The amplifiers are used to compensate loss due to fibre attenuation. You may assume that the amplifier gain exactly equals the loss due to fibre attenuation. Each amplifier has a 3 dB noise figure, the SNR at the transmitter is 10^8, and there is a 30 dB transmission loss between amplifiers along the fibre. Compute the SNR at the output of the fibre. (3 marks)

(b) A 1-Mb/s NRZ pulse train is transmitted along a shot-noise limited system at λ = 0.82 μm. The receiver has negligible dark current and an ideal quantum efficiency of unity. How many photons per bit must be incident on the photodetector if the desired BER is 10^{-4}? Compute the optic power incident upon the detector. (3 marks)

(c) 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. You may assume the noisy resistor can be modelled by a single noise source in series with a lumped ideal resistor. Let the mean square voltage noise of the source be $\langle e_n^2 \rangle$. Let the mean square noise across the capacitor be $\langle v_n^2 \rangle$. Let the mean square noise current through the loop be $\langle i_n^2 \rangle$. The angle brackets represent temporal averages. By KVL, over a time window τ, we can write $v_n(t,\tau) + i_n(t,\tau)R = e_n(t,\tau)$. You may assume that the windowed Fourier transform of this equation is: $V_n(\omega,\tau) + I_n(\omega,\tau)R = E_n(\omega,\tau)$. 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)

(ii) Explain why we cannot take the limit inside the integral without first taking ensemble averages. Then 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)

(iii) 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)

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

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

Now by substituting this into $\left|V_n\right|^2 = \dfrac{\left|E_n\right|^2}{1+(\omega RC)^2}$, show that $\left\langle v_n^2 \right\rangle = \dfrac{1}{2\pi} S_0 \dfrac{\pi}{2RC}$.

(2 marks)

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

(2 marks)

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

4.

(a) Prove that the maximum value of a/λ is 1.6 times larger for a single-mode parabolic index GRIN fibre than for a single mode SI fibre, where the symbols have their usual meanings. (5 marks)

(b) The equilibrium length of a multimode fibre is 2 km. The modal pulse spread is 25 ns for a 1 km length. The light source emits at 800 nm and has a spectral width of 50 nm. Compute the optical 3 dB bandwidth of a 5 km length of this fibre. You may assume that at λ_0 = 800 nm, M = 115 ps/nm/km. (5 marks)

(c) Briefly explain why mode mixing reduces modal distortion, and what happens when the equilibrium length is reached. (4 marks)

(d) A fibre has a numerical aperture, NA = 0.2588. A light source is coupled to it which emits 75% of its light into a 60 degree full-cone angle, 50% into a 30 degree cone and 25% into a 15 degree cone.

(i) What is the coupling efficiency when this source and fibre are connected? (2 marks)

(ii) If the refractive index of the core is 1.45, what is the loss due to reflections? (4 marks)

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