UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2023/2024

COURSE NAME	: OPTICAL COMMUNICATION
COURSE CODE	: BEJ41303
PROGRAMME CODE	: BEJ
EXAMINATION DATE	: JULY 2024
DURATION	: 3 HOURS
INSTRUCTION	: 1. ANSWER ALL THE QUESTIONS 2. THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSED BOOK** ☐ Open book ☒ Closed book 3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

THIS QUESTION PAPER CONSISTS OF **SEVEN (7)** PAGES

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Q1 (a) Discuss the cause of extrinsic absorption in optical fibers.

(2 marks)

(b) A single-mode step index fiber has core and cladding refractive indices of 1.498 and 1.495 respectively. Estimate:

(i) the core diameter required for the fiber to permit its operation over the wavelength range from 1.48 μm to 1.60 μm

(4 marks)

(ii) the new fiber core diameter to enable single-mode transmission at a wavelength of 1.30 μm

(2 marks)

(c) Chromatic or intramodal dispersion consists of material and waveguide dispersion. Compare and contrast the material and waveguide dispersion mechanism. Describe with the aid of simple diagrams.

(4 marks)

(d) A 6 km optical link consists of a multimode step-index fiber with a core refractive index of 1.5 and a relative index difference of 1%. Estimate

(i) the delay difference between the slowest and fastest modes at the fiber output

(2 marks)

(ii) the rms pulse broadening due to intermodal dispersion on the link

(2 marks)

(iii) the maximum bit rate that may be obtained without substantial errors on the link assuming only intermodal dispersion

(2 marks)

(iv) the bandwidth-length product corresponding to (d) (iii)

(2 marks)

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Q2 (a) Discuss the requirement for population inversion in order that stimulated emission may dominate over spontaneous emission in a laser. Illustrate your answer with the aid of energy level diagram provided that the laser has four energy levels.

(4 marks)

(b) The laser cavity of semiconductor lasers comes in a few types; among them are distributed feedback (DFB), vertical cavity surface-emitting (VCSEL) and Fabry-Perot (FP) laser. Differentiate DFB, VCSEL and FP lasers in terms of their structure and mechanism.

(6 marks)

(c) A planar light emitting diode (LED) is fabricated from gallium arsenide which has a refractive index of 3.6.

(i) Calculate the optical power emitted into air as a percentage of the internal optical power for the device when the transmission factor at the crystal-air interface is 0.68.

(2 marks)

(ii) When the optical power generated internally is 50% of the electric power supplied, determine the external power efficiency.

(2 marks)

(d) The light output from the GaAs LED of (c) is coupled into a step index fiber with a numerical aperture of 0.2, a core refractive index of 1.4 and a diameter larger than the diameter of the device. Estimate

(i) the coupling efficiency into the fiber when the LED is in close proximity to the fiber core,

(1 mark)

(ii) the optical loss in decibels, relative to the power emitted from the LED, when coupling the light output into the fiber,

(2 marks)

(iii) the loss relative to the internally generated optical power in the device when coupling the light output into the fiber in which there is a small air gap between the LED and the fiber core.

(3 marks)

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Q3 (a) Explain the detection process in the p-n photodiode. Compare this device with the p-i-n photodiode.

(4 marks)

(b) A p-n photodiode has a quantum efficiency of 50% at a wavelength of 0.9 μm. Calculate

(i) its responsivity at 0.9 μm,

(2 marks)

(ii) the received optical power if the mean photocurrent is 10^{-6} A,

(2 marks)

(iii) the corresponding number of received photons at this wavelength.

(2 marks)

(c) A germanium avalanche photodiode (APD) with x=1.0 operates at a wavelength of 1.35 μm where its responsivity is 0.45 AW^{-1}. The dark current is 200 nA at the operating temperature of 250 K and the device capacitance is 3 pF. Estimate the maximum possible signal-to-noise ratio (SNR) when the incident optical power is 8 x 10^{-7} W and the post-detection bandwidth without equalization is 560 MHz.

(10 marks)

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Q4 (a) Noise Figure is one of important performance parameters for optical amplifiers. Justify the requirement for low Noise Figure for optical amplifiers and thus optical communication.

(5 marks)

(b) Outline erbium-doped fiber amplifier (EDFA) designs incorporating both a co-propagating and counter-propagating pump. State the main advantages for each configuration.

(6 marks)

(c) A single-mode step index fiber with a fusion splice has the following parameters

Fiber normalized frequency = 1.9
Fiber core refractive index = 1.46
Splice lateral offset = 0.5 μm
Splice lateral offset loss = 0.05 dB
Splice angular misalignment = 0.3°
Splice angular misalignment loss = 0.04 dB

Estimate:

(i) the fiber core diameter

(6 marks)

(ii) the numerical aperture of the fiber

(3 marks)

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Q5 (a) A digital single-mode optical fiber system is designed for operation at a wavelength of 1.5 μm and a transmission rate of 560 $Mbits^{-1}$ over a distance of 50 km without repeaters. The single-mode injection laser is capable of launching a mean optical power of -13 dBm into the fiber cable which exhibits a loss of 0.25 $dBkm^{-1}$. In addition, average splice losses are 0.1 dB at 1 km intervals. The connector loss at the receiver is 0.5 dB and the receiver sensitivity is -39 dBm. Finally, an extinction ratio penalty of 1 dB is predicted for the system. Perform an optical power budget for the system and estimate the safety margin.

(10 marks)

(b) A simple analog optical fiber link operates over a distance of 15 m. The transmitter comprises an LED source which emits an average of 1 mW of optical power into air when the drive current is 40 mA. Plastic fiber cable with an attenuation of 500 $dBkm^{-1}$ at the transmission wavelength is utilized. The minimum optical power level required at the receiver for satisfactory operation of the system is 5 μW. The coupling losses at the transmitter and receiver are 8 dB and 2 dB respectively. In addition, a safety margin of 4 dB is necessary. Estimate the minimum LED drive current required to maintain satisfactory system operation.

(10 marks)

- END OF QUESTIONS -

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APPENDIX

Constant

Velocity of light in vacuum, $c = 3 \times 10^8$ ms^{-1}
Plank constant, $h = 6.626 \times 10^{-34}$ Js
Boltzmann constant, $k = 1.381 \times 10^{-23}$ JK^{-1}
Absolute temperature, T = 17 ^{o}C or 290 K

Formula

$$V = \frac{2\pi}{\lambda} a n_1 (2\Delta)^{\frac{1}{2}},\ \tau_g = \frac{1}{c}\left(n_1 - \frac{\lambda d n_1}{d\lambda}\right),\ \tau_m = \frac{L}{c}\left(n_1 - \frac{\lambda d n_1}{d\lambda}\right),\ \sigma_m = \frac{\sigma_\lambda L}{c}\left(\lambda \frac{d^2 n_1}{d\lambda^2}\right)$$

$$\tau_s = \frac{(NA)^2}{2cn_1},\ \tau_g = \frac{n_1 \Delta^2}{8c},\ \sigma_s = \frac{L n_1 \Delta}{2\sqrt{3}c},\ \sigma_s = \frac{L(NA)^2}{4\sqrt{3}n_1 c},\ \sigma_T = (\sigma_m^2 + \sigma_s^2)^{\frac{1}{2}}\ ,\ \delta T_S = \frac{L n_1 \Delta}{c}$$

$$B_T = \frac{0.2}{\sigma}\text{ bits/sec},\ B_T = \frac{1}{2\tau}\text{ bits/sec},\ BW = B_T(RZ),\ BW = \frac{1}{2}B_T(NRZ)$$

$$\eta_{int} = \frac{1}{1+\tau_r/\tau_{nr}} = \frac{\tau}{\tau_r},\ P_{int} = \eta_{int}\frac{h\nu I_p}{e} = \eta_{int}\frac{hcI_p}{e\lambda},\ \eta_{ep} = \frac{P_e}{P},\ P = IV,\ R = \frac{I_P}{P_0},\ R = \frac{\eta e \lambda}{hc}$$

$$n = \frac{P_0}{hf} = \frac{P_0 \lambda}{hc},\ P_e = \frac{P_{int} F n^2}{4n_x^2},\ r_e = \frac{I_p}{e},\ r_p = \frac{P_o}{hf},\ L = \frac{\lambda}{2n}q,\ \Delta\lambda = \frac{\lambda^2}{2nL},\ \Delta f = \frac{c}{2nL}$$

$$\overline{i_{th}^2} = \frac{4kTB}{R}(A^2),\ \overline{i_{shot}^2} = 2eB(I_p + I_d)(A^2),\quad SNR = \frac{I_p^2}{\overline{i_{shot}^2} + \overline{i_{th}^2} + \overline{i_{amp}^2}},$$

$$SNR = \frac{M^2 I_p^2}{\overline{i_{shot}^2} M^{2+x} + \overline{i_{th}^2} + \overline{i_{amp}^2}}\ ,\ SNR = \frac{I_p^2}{\overline{i_{TS}^2} + \overline{i_t^2} F_n}\ ,\ M_{op}^3 = \frac{4KTF_n}{xeR_L(I_p + I_d)}$$

$$P_e = \frac{1}{2} erfc\left(\frac{\sqrt{SNR}}{2\sqrt{2}}\right),\ P_e = \frac{1}{2} erfc\left(\frac{I_p}{2\sqrt{2\sigma_s}}\right),\ \sigma_s^2 = 2qI_p\Delta f \qquad A = 10\log_{10}\frac{P_i}{P_0}$$

$$R_L = \frac{1}{2\pi B(C_d + C_a)},\ T_l = 2.17\left(\frac{y}{\omega}\right)^2,\ \omega = a\frac{\left(0.65 + 1.62V^{-\frac{3}{2}} + 2.88V^{-6}\right)}{2^{\frac{1}{2}}},$$

$$T_a = 2.17\left(\frac{\theta \omega n_1 V}{a(NA)}\right)^2 dB$$

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