



UNIVERSITI TUN HUSSEIN ONN MALAYSIA

**FINAL EXAMINATION
SEMESTER II
SESSION 2022/2023**

- COURSE NAME : OPTICAL COMMUNICATION
- COURSE CODE : BEJ 41303
- PROGRAMME CODE : BEJ
- EXAMINATION DATE : JULY/AUGUST 2023
- DURATION : 3 HOURS
- INSTRUCTION : 1. ANSWER ALL THE QUESTIONS
2. THIS FINAL EXAMINATION IS CONDUCTED VIA **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 (2 marks)
 - (ii) the new fiber core diameter to enable single-mode transmission at a wavelength of 1.30 μm (4 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 8×10^{-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 $1.5 \mu\text{m}$ 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 $5 \mu\text{W}$. 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 QUESTION -

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Constant

Velocity of light in vacuum, $c = 3 \times 10^8 \text{ ms}^{-1}$

Plank constant, $h = 6.626 \times 10^{-34} \text{ Js}$

Boltzmann constant, $k = 1.381 \times 10^{-23} \text{ JK}^{-1}$

Absolute temperature, $T = 17^\circ \text{C}$ or 290 K

Formula

$$V = \frac{2\pi}{\lambda} an_1(2\Delta)^{\frac{1}{2}}, \tau_g = \frac{1}{c} \left(n_1 - \frac{\lambda dn_1}{d\lambda} \right), \tau_m = \frac{L}{c} \left(n_1 - \frac{\lambda dn_1}{d\lambda} \right), \sigma_m = \frac{\sigma_\lambda L}{c} \left(\lambda \frac{d^2 n_1}{d\lambda^2} \right)$$

$$\tau_s = \frac{(NA)^2}{2cn_1}, \tau_g = \frac{n_1 \Delta^2}{8c}, \sigma_s = \frac{Ln_1 \Delta}{2\sqrt{3}c}, \sigma_s = \frac{L(NA)^2}{4\sqrt{3}n_1 c}, \sigma_T = (\sigma_m^2 + \sigma_s^2)^{\frac{1}{2}}, \delta T_s = \frac{Ln_1 \Delta}{c}$$

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

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

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

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

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

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

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

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

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