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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2019/2020

COURSENAME	:	OPTICAL COMMUNICATIONS
COURSE CODE	:	BEB 41603
PROGRAMME	:	BEJ
EXAMINATION DATE	:	DECEMBER 2019 / JANUARY 2020
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS

THIS QUESTION PAPER CONSISTS OF **EIGHT (8)** PAGES

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Q1 (a) Make comparison between optical fiber communication and electrical cable transmission with respect to interference, security and flexibility.

(3 marks)

(b) Given that the refractive index of diamond and water are 2.42 and 1.33 respectively. Justify why the refractive index of diamond is higher than water. Relate your answer with the wave propagation in the medium.

(3 marks)

(c) (i) An optical fiber has relative refractive index difference of 1.5% and core refractive index of 1.48. Estimate the maximum core diameter for the optical fiber operates in single-mode operation.

(4 marks)

(ii) Estimate the new maximum core diameter for single-mode operation when the relative refractive index difference is reduced by a factor of 10.

(3 marks)

(d) A multimode graded index fiber exhibits total pulse broadening of 0.1 μs over a distance of 15 km. Estimate:

(i) The maximum possible bandwidth on the link assuming no intersymbol interference and the utilized code is Return-to-Zero (RZ)

(3 marks)

(ii) The pulse dispersion per unit length

(2 marks)

(iii) The bandwidth-length product for the fiber

(2 marks)

Q2 (a) Make comparison between spontaneous and stimulated emission in optical fibers. Illustrate your answer with the aid of energy level diagram.

(4 marks)

(b) Explain the need to forward-bias the P-N junction for light emission of LEDs and lasers using a suitable diagram.

(4 marks)

(c) Formulate a mathematical relationship for 3 dB electrical bandwidth and 3 dB optical bandwidth for an optical fiber communication system.

(6 marks)

(d) The minority carrier recombination lifetime for an LED is 5 ns. When a constant DC drive current is applied to the device, the optical output power is 300 μW. Estimate:

(i) the optical output power when the LED is modulated with an rms drive current that has frequency of 100 MHz.

(2 marks)

(ii) the 3-dB optical bandwidth of the LED.

(2 marks)

(iii) the 3-dB electrical bandwidth of the LED.

(2 marks)

Q3 (a) Describe a photodiode response time of a rectangular input pulse for the following case using appropriate diagram.

Case 1: large photodiode capacitance and wide depletion layer

Case 2: small photodiode capacitance and narrow depletion layer

(4 marks)

(b) An InGaAs pin photodiode has the following parameters at a wavelength of 1300 nm :

- Dark current : 4 nA
- Quantum efficiency : 0.9
- Load resistance : 1000 Ω
- Receiver bandwidth : 20 MHz

(i) Compare the rms current for quantum noise, dark current noise and thermal noise at temperature of 20 °C

(10 marks)

(ii) Estimate the signal to noise ratio (SNR) in dB

(2 marks)

(c) A silicon avalanche photodiode has a quantum efficiency of 65% at a wavelength of 900 nm. Suppose 0.5 μW of optical power produces a multiplied photocurrent of 10 μA. Determine the multiplication M for this photodiode.

(4 marks)

Q4 (a) Consider an InGaAsP semiconductor optical amplifier that has the parameter values in **Table Q4(a)**. If a 100 mA bias current is applied, calculate

(i) The pumping rate

(2 marks)

(ii) The maximum (zero-signal) gain

(3 marks)

(iii) The saturation photon density

(2 marks)

(iv) The photon density if a 1 μW signal at 1310 nm enters the amplifier

(3 marks)

(b) The principal role of all star couplers is to combine the powers from N inputs and divide them equally among M output ports. Construct a 8 x 8 star coupler using 3 dB coupler and estimate the total loss experienced by a signal as it passes through it. Assume 7 % of the power lost occurred in each 3 dB coupler.

(10 marks)

Q5 You are required to construct a computer to computer communication link with operating bit rate of 100 Mbit/s based on non-return to zero (NRZ). The components and their parameters are given in **Table Q5**. The fiber rise time is an approximation of the delay difference or pulse spread due to dispersion impairment in optical fiber. Estimate :

(i) the maximum distance of your designed communication link.

(17 marks)

(ii) the LED optical power needs to be coupled into the optical fiber.

(3 marks)

Assume that all optical fiber splices, the coupling loss (between optical fiber and LED or photodetector), and the system margin are 7 dB.

- END OF QUESTIONS -

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Table Q4(a)

Parameter	Value
Active area width, w	5 μm
Active area thickness, d	0.5 μm
Amplifier length, L	200 μm
Confinement factor, Γ	0.3
Time constant, τ_r	1 ns
Gain coefficient, a	1×10^{-20} m^2
Group velocity, υ_g	2×10^8 m/s
Threshold density, n_{th}	1×10^{24} m^{-3}

Table Q5

Transmitter	LED λ=1310 nm rise time = 3 ns, spectral width = 100 nm
Receiver	p-i-n rise time = 3 ns, receiver sensitivity = -30 dBm at BER of 10^{-9}
Fiber	Graded index optical fiber Core refractive index = 1.491 Relative refractive index difference = 2 % Core refractive index profile = 2 attenuation = 0.6 dB/km at 1310 nm zero dispersion wavelength = 1300 nm zero dispersion slope= 0.097 ps/nm^2-km

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Constants

Planck's constant, h = 6.626 x 10^{-34} J.s

Boltzmann's constant, K=1.381 x 10^{-23} J.K^{-1}

Electron charge, e =1.602 x 10^{-19} Coulomb

Velocity of light in vacuum, c = 2.998 x 10^{8} m/s

Formula

$$n_1 \sin\theta_1 = n_2 \sin\theta_2,\ V = \frac{2\pi}{\lambda} a n_1 (2\Delta)^{\frac{1}{2}},\ \tau_g = \frac{1}{c}\left(n_1 - \frac{\lambda dn_1}{d\lambda}\right),\ \tau_m = \frac{L}{c}\left(n_1 - \frac{\lambda dn_1}{d\lambda}\right),\ \sigma_m = \frac{\sigma_\lambda L}{c}\left(\lambda \frac{d^2 n_1}{d\lambda^2}\right)$$

$$\tau_s = \frac{L(NA)^2}{2cn_1},\ \tau_g = \frac{Ln_1\Delta^2}{8c},\ \sigma_s = \frac{Ln_1\Delta}{2\sqrt{3}c},\ \sigma_s = \frac{L(NA)^2}{4\sqrt{3}n_1 c},\ \sigma_T = (\sigma_m^2 + \sigma_s^2)^{\frac{1}{2}},\ \tau_{chrom} = |D| \times L \times \Delta\lambda$$

$$D(\lambda) = \frac{S_0}{4}\left(\lambda - \frac{\lambda_{ZD}^4}{\lambda^3}\right) ps/nm.km,\ B_T = \frac{0.2}{\sigma} bits/\sec,\ B_T = \frac{1}{2\tau} bits/\sec,\ BW = B_T(RZ),$$

$$BW = \frac{1}{2} B_T(NRZ),\ \eta_{int} = \frac{1}{1 + \tau_r/\tau_{nr}} = \frac{\tau}{\tau_r},\ P_{int} = \eta_{int} \frac{I_p}{e} h\upsilon = \eta_{int} \frac{hcI_p}{e\lambda},\ \eta_{ep} = \frac{P_e}{P}, where\ P = IV,$$

$$\eta_{ext} = \eta_{int} FtT\quad F = \frac{n_a^2}{2n_S^2},\ t = \frac{4n_S n_a}{(n_S + n_a)^2},\ T = 1 - a_S,\ P_e = \frac{P_{int} F n^2}{4n_x^2},\ r_e = \frac{I_p}{e},\ r_p = \frac{P_o}{hf},\ R = \frac{\eta e \lambda}{hc} = \frac{I_p}{P_0},$$

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

$$SNR = \frac{S}{N} = \frac{M^2 I_p^2}{\overline{i_{shot}^2} M^{2+x} + \overline{i_{th}^2} + \overline{i_{amp}^2}}\quad P_e(\omega) = \frac{P_{dc}}{[1+(2\pi f\tau)^2]^{\frac{1}{2}}},\ \Delta\lambda = \frac{\lambda^2}{c}\Delta f\quad \Lambda = \frac{\lambda_B}{2_n},\ L = \frac{\lambda}{2n} q,\ \Delta\lambda = \frac{\lambda^2}{2nL},$$

$$\Delta f = \frac{c}{2nL},\ R_p = \frac{I}{qwdL},\ g_0 = \Gamma a \tau_r \left(R_p - \frac{n_{th}}{\tau_r}\right),\ N_{ph} = \frac{P_S}{v_g h\upsilon wd},\ N_{ph:sat} = \frac{1}{\Gamma a v_g \tau_r}$$

$$Splitting\ loss = -10 log\left(\frac{1}{N}\right),\ Excess\ loss = -10 log\left(F_T^{log_2 N}\right),\ f_{3dB} = (2\pi R_L C_d)^{-1},\ \tau = \frac{0.7}{B_{NRZ}},,$$

$$t_{PD} = 2.19 R_L C_D,\ \tau_s = \sqrt{\tau_f^2 + \tau_{TX}^2 + \tau_{RX}^2},$$

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