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FINAL EXAMINATION
SEMESTER I
SESSION 2016/2017

COURSENAME	:	OPTICAL COMMUNICATIONS
COURSE CODE	:	BEB 41603
PROGRAMME	:	BEJ
EXAMINATION DATE	:	DECEMBER 2016 / JANUARY 2017
DURATION	:	3 HOURS
INSTRUCTION	:	SECTION A: ANSWER **ALL** QUESTIONS SECTION B: ANSWER **TWO (2)** QUESTIONSONLY SECTION C: ANSWER **ONE (1)** QUESTION ONLY

THIS QUESTION PAPER CONSISTS OF **NINE (9)** PAGES

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SECTION A: ANSWER ALL QUESTIONS

Q1 Two 50/125 μm graded index fiber have a core axis refractive index of 1.49 and a relative index difference of 1%. First fiber (Fiber A) and second fiber (Fiber B) are developed with the refractive index profile of 2 and 4, respectively.

(i) Sketch the refractive index profile diagram for both fiber. You must label the value of refractive index at core axis and cladding.

(ii) Calculate the number of modes at operating wavelength of 850 nm for both fiber.

The refractive index variation in a graded index fiber as follows:

$$n(r) = \begin{cases} n_1\left[1 - 2\Delta\left(\dfrac{r}{a}\right)^{\alpha}\right]^{1/2} & \textit{for} \quad 0 \le r \le a \\ n_2 & \textit{for} \quad r \ge a \end{cases}$$

(10 marks)

Q2 (a) Explain the importance of LED and laser play in modern optical communication system.

(6 marks)

(b) Analyze the delay difference per kilometer due to intermodal dispersion mechanism for the following fibers:

(i) A multimode step index fiber with core index of 1.46 and relative index difference of 1.2%.

(ii) A graded index fiber having an optimum parabolic index profile and the same core index as the step index fiber in **Q2(b)(i)** but with relative index difference of 0.6%.

(4 marks)

Q3 (a) Explain the detection principle of photodiode with an aid of diagram.

(5 marks)

(b) A p-n photodiode has a quantum efficiency of 70% when photons of energy 1.52×10^{-19} J. Calculate;

(i) the operating wavelength of the photodiode.

(ii) the incident optical power that is required to induce a photocurrent of 3 μA.

(5 marks)

Q4 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 5% of the power lost occurred in each 3 dB coupler.

(10 marks)

SECTION B: ANSWER TWO (2) QUESTIONS ONLY

Q5 (a) Group Velocity Dispersion (GVD) limits the performance of optical system over conventional single mode fiber. With an aid of suitable diagram, describe the implementation of Dispersion Compensating Fiber (DCF) in optical system to eliminate the GVD effect.

(8 marks)

(b) A Burrus type GaAs LED is coupled to a step index fiber core diameter larger than the emitting area of the LED, using transparent bonding cement with refractive index of 1.5. The diode is forward biased with a current of 100 mA and a voltage of 1.5 V, and each emitted photon possesses energy of 1.42 eV. This LED has radiative and non-radiative recombination times of 120 ns and 100 ns, respectively. The step index fiber has core refractive index of 1.46 and relative refractive index of 2%. Refractive index of GaAs is 3.7 and the absorption in GaAs is 10%. Calculate;

(i) the internal quantum efficiency,

(ii) the external quantum efficiency,

(iii) the external power efficiency.

(12 marks)

Q6 (a) The photodiode incorporated into an optical receiver has a quantum efficiency of 60% when photons of energy 1.3×10^{-19} J are incident upon it. The dark current in the device at this operating point is 2 nA and the load resistance is 4 kΩ at a temperature of 20°C. The incident optical power is 3.5 μW, the post detection bandwidth is 6 MHz and the noise figure for the amplifier is 2.2 dB. The capacitance for photodiode and amplifier input is same. Analyse the rms thermal and shot noise current of this optical receiver.

(10 marks)

(b) On-off keying (OOK) transmission in optical communication system can be implemented using direct modulation or indirect modulation technique at transmitter side. Describe both technique with an aid of diagram.

(5 marks)

(c) Advance modulation technique is a potential candidate for upgrading the capacity of data transportation per channel wavelength in optical communication system. Give your opinion to support this statement.

(5 marks)

Q7 (a) Compare between a p-i-n photodiode and an avalanche photodiode (APD).

(4 marks)

(b) An APD has a quantum efficiency of 50% at 1.3 μm. When illuminated with optical power of 0.4 μW at this wavelength, it produces an output photocurrent of 8 μA from the device. Calculate the multiplication factor of the APD.

(6 marks)

(c) A 5 Gbps optical communication link is designed to operate at 300 km length. Optical amplifier with the noise figure of 5 dB is required for each span in this link to compensate the fiber loss. Calculate the number of spans in the communication link to obtain the optical signal to noise ratio of 20 dB by assuming the launching power is 0 dBm and the fiber attenuation is 0.2 dB/km.

(5 marks)

(d) Briefly explain the concept of wavelength division multiplexing with an aid of suitable diagram.

(5 marks)

SECTION C: ANSWER ONE (1) QUESTION ONLY

Q8 As an engineer, you are required to design a low cost computer to computer communication link with operating bit rate of 100 Mbps based on non-return to zero (NRZ). The link should be constructed using Graded Index Optical Fiber, an infrared LED, and a photodetector. The parameters of the components are given in **Table Q8**. Estimate :

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

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

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

(20 marks)

Q9 XYZ company will construct a telecommunication infrastructure of 10 Gbps using 40 km optical fiber link. As an engineer in this company, you are assigned to design the link based on the available components as shown in **Table Q9**. Fiber splice will be used to join the optical fiber. The splice loss is 0.2 dB/splice. Connectors are required at transmitter and receiver. Suggest your setup based on the provided components by considering power and rise time budget if NRZ modulation is used. The power margin of 6 dB should be added in your estimation.

(20 marks)

- END OF QUESTIONS -

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Table Q8: Parameters

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 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

Table Q9: Parameters

Transmitter 1	Direct modulated DFB laser λ=1570 nm output power = 1 mW rise time = 20 ps spectral width = 0.1 nm
Transmitter 2	Continuous wave DFB laser λ=1570 nm output power = 1 mW rise time = 20 ps spectral width = 0.01 nm
Receiver 1	InGaAs p-i-n rise time = 20 ps, receiver sensitivity = -17 dBm at BER of 10^{-9}
Receiver 2	InGaAsAPD rise time = 25 ps, receiver sensitivity = -24 dBm at BER of 10^{-9}
Optical Modulator	Insertion loss = 6 dB
Fiber	Single mode fiber available lengths = 5 km / drum attenuation = 0.2 dB/km at 1570 nm dispersion = 17ps/(km.nm) at 1570 nm
Connector	Loss = 1 dB/connector

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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

$V=\frac{2\pi}{\lambda}an_1(2\Delta)^{\frac{1}{2}}$	$\tau_g=\frac{1}{c}\left(n_1-\frac{\lambda dn_1}{d\lambda}\right)$	$\tau_m=\frac{L}{c}\left(n_1-\frac{\lambda dn_1}{d\lambda}\right)$	$\sigma_m=\frac{\sigma_\lambda L}{c}\left(\lambda\frac{d^2n_1}{d\lambda^2}\right)$
$\tau_s=\frac{(NA)^2}{2cn_1}$	$\tau_g=\frac{n_1\Delta^2}{8c}$	$\sigma_s=\frac{Ln_1\Delta}{2\sqrt{3}c}$	$\sigma_s=\frac{L(NA)^2}{4\sqrt{3}n_1c}$
$\sigma_T=(\sigma_m^2+\sigma_s^2)^{\frac{1}{2}}$	$B_T=\frac{0.2}{\sigma}bits/\sec$	$B_T=\frac{1}{2\tau}bits/\sec$	$BW=B_T(RZ)$
$BW=\frac{1}{2}B_T(NRZ)$	$\eta_{int}=\frac{1}{1+\tau_r/\tau_{nr}}=\frac{\tau}{\tau_r}$	$P_{int}=\eta_{int}\frac{I_p}{e}h\upsilon=\eta_{int}\frac{hcI_p}{e\lambda}$	$\eta_{ep}=\frac{P_e}{P}, where\ P=IV$
$\eta_{ext}=\eta_{int}FtT$	$F=\frac{n_a^2}{2n_S^2}$	$t=\frac{4n_Sn_a}{(n_S+n_a)^2}$	$T=1-a_S$
$P_e=\frac{P_{int}Fn^2}{4n_x^2}$	$r_e=\frac{I_p}{e}$	$r_p=\frac{P_o}{hf}$	$L=\frac{\lambda}{2n}q$
$\Delta\lambda=\frac{\lambda^2}{2nL}$	$\Delta f=\frac{c}{2nL}$	$R=\frac{\eta e\lambda}{hc}=\frac{I_p}{P_0}$	$\overline{i_{shot}^2}=2eB(I_p+I_d)(A^2)$
$\overline{i_{th}^2}=\frac{4KTB}{R}(A^2)$	$SNR=\frac{S}{N}=\frac{I_p^2}{\overline{i_{shot}^2}+\overline{i_{th}^2}+\overline{i_{amp}^2}}$		$SNR=\frac{S}{N}=\frac{M^2I_p^2}{\overline{i_{shot}^2}M^{2+x}+\overline{i_{th}^2}+\overline{i_{amp}^2}}$
$f_{3dB}=(2\pi R_LC_d)^{-1}$	$\tau=\frac{0.7}{B_{NRZ}}$	$\tau_{chrom}=\lvert D\rvert\times L\times\Delta\lambda$	$t_{PD}=2.19R_LC_D$
$\tau_s=\sqrt{\tau_f^2+\tau_{TX}^2+\tau_{RX}^2}$	$\Lambda=\frac{\lambda_B}{2_n}$	$V=\frac{2\pi\ a}{\lambda}\sqrt{n_1^2-n_2^2}$	$n_1\sin\theta_1=n_2\sin\theta_2$
$D(\lambda)=\frac{S_0}{4}\left(\lambda-\frac{\lambda_{ZD}^4}{\lambda^3}\right)ps/nm.km$	$\Delta\lambda=\frac{\lambda^2}{c}\Delta f$	$OSNR=P_{in}+58-L_S-NF-10\log(N_A)$	