MACHAKOS UNIVERSITY

University Examinations for 2021/2022

SCHOOL OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

FIFTH YEAR EXAMINATIONS FOR BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 529: FIBER-OPTIC COMMUNICATION

DATE: 9/12/2021 **TIME: 8.30-10.30 AM**

INSTRUCTIONS
ANSWER QUESTION ONE AND ANY OTHER TWO

QUESTION ONE (30 MARKS)

a) A fiber whose length is 0.1Km has input power of 0.01 mW and output power of 0.009 mW. Calculate the fiber loss in decibels per kilometer. (3 marks)

b) Data is to be transmitted through an optical fiber link whose length is 100,000 m with a fiber loss of 0.0002dB/m. The optic fiber link has five splices with 0.05 dB loss per splice and two connectors with 0.2 dB per connector. The receiver sensitivity is 20μW. Compute the transmitter power in both mW and dBm.. (5 marks)

c) The refractive index of the core of a step-index optic fiber link is 1.5, while the refractive index of its cladding is 1.4967. This fiber is used to transmit light at 1.55 μm. The radius of the core is 5 μm. Based on this information;

i) How many modes can propagate in the fibre?

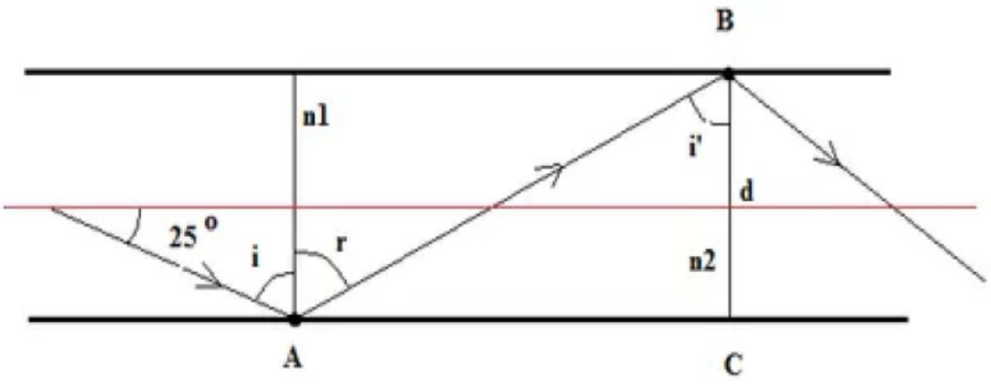
ii) Which are the two main causes of dispersion in this fibre?

iii) Determine the dispersion due to these two mechanisms.

Note: For your calculations, material dispersion is assumed to be zero for waveguide dispersion. (5 marks)

d) Determine the turn on time for a fiber laser whose I_{bias}=0.005 A, $I_{threshold}$=0.01 A and I_{step}=0.01 A. Further, take the charge carriers life time as one nanoseconds and one picoseconds for the photons. (5 marks)

e) Study the diagram below and answer the question that follow. (6 marks)



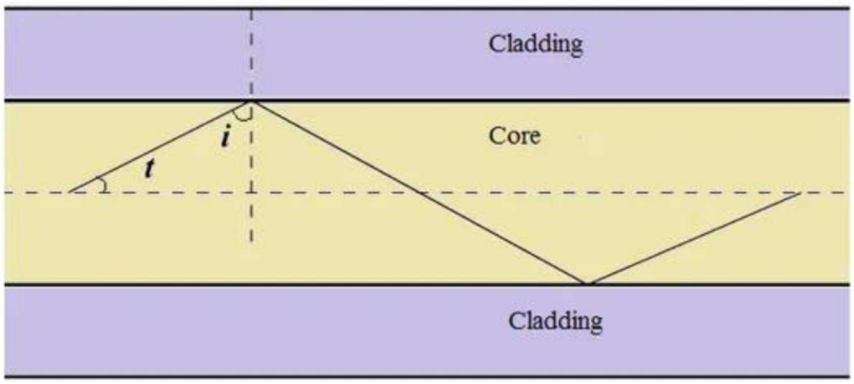
i) Determine the reflection angle at A

ii) Determine the reflection angle B.

iii) If d =0.04m and the length of the boundaries in the above diagram is 3m, calculate the number of reflections that take place between the two boundaries.

iv) If the length of the boundaries and distance between the boundaries is fixed, what strategies can be applied to reduce the number of reflections?

f) Study the fiber schematic below and answer the questions that follow. (6 marks)



If the refractive indexes of the cladding and the core 1.4 and 1.5 respectively;

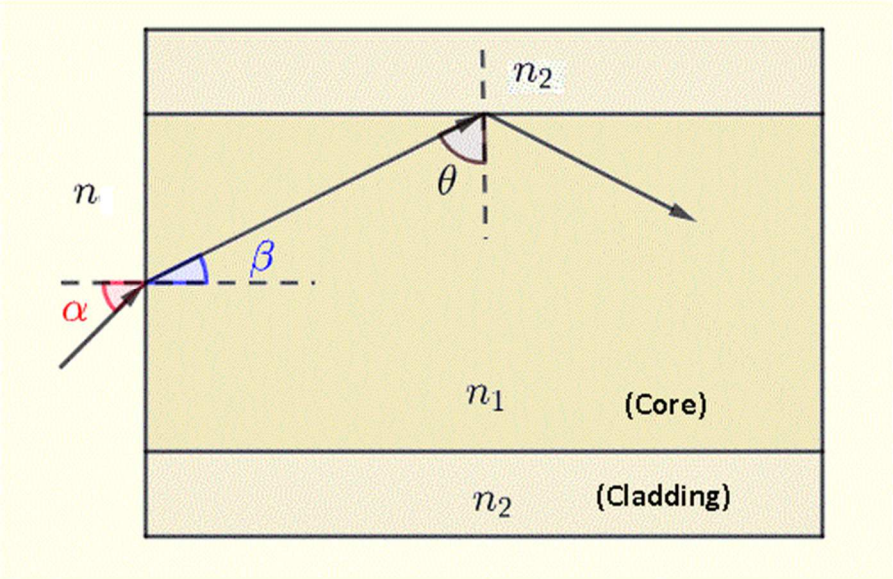
i. Determine light velocity in the fiber core.

ii. Compute the critical angle at the core and cladding boundary.

iii. Determine the angle that light rays entering the fiber must make for total internal reflection to take place.

QUESTION TWO (20 MARKS)

a) Study the diagram below and answer the questions that follow. (6 marks)



Compute the acceptance and critical angles and the numerical aperture if n=1, n_2=1.45 and n_1=1.46.

b) Determine the refractive indexes n_1 and n_2 in Question 2(a) above, corresponding to:

$$\alpha_{max} = \sin^{-1}\left(\frac{1}{n}\sqrt{n_1^2 - n_2^2}\right)$$, and

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

(6 marks)

c) A step index fiber with a core diameter of 80,000 nm and a relative index difference of 1.5% can transmit multiple modes. If the fiber is operated at a wavelength of 850 nm, calculate the number of modes that can be transmitted as normalized frequency refractive index of the core is 1.48. (5 marks)

d) A 2000m fiber that can transmit several modes has a modal dispersion of 1 ns/km. If it is used with the optic source that has a linewidth of 40 nm, for a chromatic dispersion of 100 ps/km • nm:

i. Determine the total dispersion?

ii. Determine the fiber bandwidth. (5 marks)

QUESTION THREE (20 MARKS)

a) The numerical aperture of a single mode fiber is 0.12. Determine the maximum core diameter for an operating wavelength of 1550 nanometres. (5 marks)

b) Determine the channel capacity for a multimode fiber whose refractive index has a step profile and has a refractive index of 1.46, at an operating frequency of 0. 850µm with the normalized index difference being 0.01. (5 marks)

c) An optic fiber that operates in singular mode has step refractive index of the core of 1.46. If the diameter of the core 9 µm, for a relative index difference of 0.0025, compute the cut off wavelength assuming that only a single mode of operation.. (5 marks)

d) A input power of 0.120 milliwatts is launched into a 8000m fiber. Determine the total attenuation in decibels if the power measured at the output is 0.003 milliwatts. Also, compute the total attenuation for a 10,000m fiber using the same fiber with splices at 1000m intervals, given that each splice has a total attenuation of one decibel.

(5 marks)

QUESTION FOUR (20 MARKS)

a) The spectral width of an optical diode is 0.002µm. Compute the pulse spreading for this optical diode. Also, at an operating frequency of 1.55um, calculate the pulse spreading as a result of material dispersion when the spectral width is 0.75 µm for a laser diode. Take $\left|\lambda^2 . \frac{d^2 n}{d\lambda^2}\right|$ to be 0.03 for the optical diode and 0.025 for the laser diode. (3 marks)

b) The radiative and non radiative recombination life times of minority carriers in the active region of a double heterojunction LED are 60 nsec and 90 nsec respectively. Determine the total carrier recombination life time and optical power generated internally if the peak emission wavelength is 870 nm and the drive current is 40 mA. (3 marks)

c) Calculate bit rate distance product of a graded index fiber whose core radius is 25 µm given the following refractive indices: core index $n1$ = 1.480,cladding index $n2$=1.460. Assume that the fiber operating frequency is 1300 nm and that it is used with a narrow width optical diode. Also, compute the bit rate bandwidth product in the case where the

fiber is multimode with a step refractive index given that the light output is nearly rectangular so that $\sigma \approx 0.29\ \Delta\tau$ in which case $\Delta\tau$ is the full spread. (3 marks)

d) You are given the following data for given fiber link:

Fiber link rate = 2 Gbit/s

Coding scheme: NRZ, equal probability for 1 and 0

Laser diode transmitter power output when a 1 is transmitted = 10 mW

Extinction ratio = 0.1

Operating Wavelength = 1300nm

Coupling loss between laser and fibre = 3 dB

Fibre attenuation = 1 dB/km

Fibre length = 34 km

Coupling loss between fibre and detector = 0 dB

p-i-n photodetector quantum efficieny = 80%

Receiver noise equivalent bandwidth = 1 GHz

Temperature = 290 K

Equivalent load resistance = 1 kΩ

Amplifier noise factor = 3 dB

i. From the above infromation, compute the bit error rate (BER) with optimum threshold.

ii. We now replace the p-i-n photodetector by an APD with FA(M)=M0.7 and apply a reverse bias voltage so that M = 300. We also adjust the threshold so that the error probability is equal for a received 1 and 0. Assume that the quantum efficiency, the coupling losses, the receiver bandwidth, and the equivalent load resistance remain the same. What is now the BER? (6 marks)

e) A receiver consists of an optical preamplifier and a pin-diode detector followed by an electronic amplifier. The ONE bits of the received signal have the power P1 and the ZERO bits of the received signal have the power . The bit rate B is 10 Gb/s and the electrical noise bandwidth is assumed to be B/2. The optical bandwidth is assumed to be small enough so that the amplified output signal from the optical preamplifier is much larger than the power from the amplified spontaneous emission. The optical amplification is 30 dB and nsp is 1. The efficiency of the pin-detector is 1 and its load

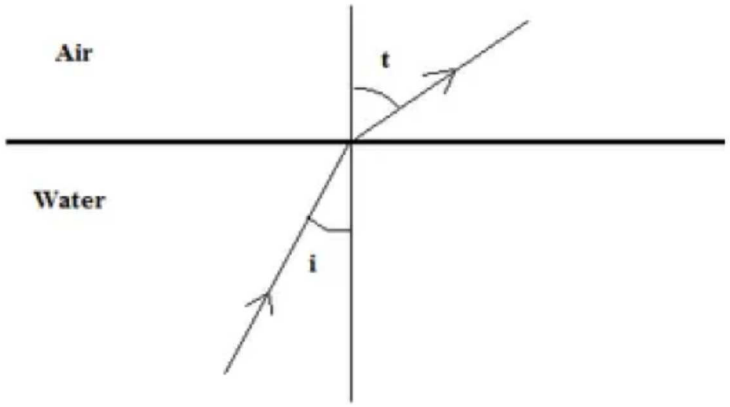
resistance is 1000 Ω. The noise factor of the electronic amplifier is a factor 3. The wavelength is 1.55 μm. How large has P1 to be in order to achieve a BER = 10^{-9}?

The optical preamplifier and the pin-detector are replaced by an APD with an amplification of 30 dB and the best possible excess noise factor. What is the value of P1 in this case?

Do not forget to motivate your approximations/assumptions. (5 marks)

QUESTION FIVE (20 MARKS)

a) Study the diagram below and answer the questions that follow. (6 marks)



i. Compute the refraction angle.

ii. It is desired that the refraction angle be no greater than 45 degrees, what value of the incidence angle meets this criteria.

iii. Determine the critical angle.

Take the refractive indexes of water and air to be 1.3 and 1 respectively and i=10 degrees.

b) A particular optic fiber system transmits at 2500Megabits per. If the system operating wavelength is 1550 nanometers, using a laser whose spectral line has a width of = 0.05 nanometres. For a dispersion coefficient of −20 ps/nm·km:

i. Calculate the pulse spread per unit distance (ps/km). (2 marks)

ii. What is the maximum length of fiber that allows the stated system bit rate? (2 marks)

iii. If the system were to operate at 10 Gb/sec NRZ, then what would be the required optical bandwidth $f_{3dB,optical}$? Hint: you don't need fiber length or $\Delta\lambda$ for this calculation. (2 marks)

iv. Given the optical bandwidth of part c), then what would be the optical frequency spread in terms of $\Delta\lambda$? What would be the maximum fiber length? (2 marks)

c) Compute the critical angle and the numerical aperture a particular fiber given the following data:

Core radius=8000nm

Core refractive index=1.46

Δ=0.003

Cladding radius=67.5µm

Also, determine the cut-off wavelength of a single mode fibre given the above data. (3 marks)

d) Given the following fiber data:

Core refractive index=1.468

Cladding refractive index=1.447

Operating wavelength=1300nm

Determine the core radius for this fiber. (3 marks)