# MACHAKOS UNIVERSITY

**University Examinations for 2023/2024 Academic Year**

**SCHOOL OF ENGINEERING AND TECHNOLOGY**

**DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING**

**FIFTH YEAR SECOND SEMESTER EXAMINATION FOR**

**BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONICS ENGINEERING**

**EEE 529: FIBER-OPTIC COMMUNICATION**

**DATE:** **TIME:**

**INSTRUCTIONS**

1. This paper consists of **FIVE** questions.
2. Answer **QUESTION ONE** and **ANY OTHER TWO** questions.
3. All workings must be clearly shown.
4. The following constants may be useful: Planck's constant $h = 6.626 \times 10^{-34}$ Js, Boltzmann constant $1.381 \times 10^{-23}\ \mathrm{m^2\,kg\,s^{-2}\,K^{-1}}$, $q = 1.602 \times 10^{-19}\ \mathrm{C}$, $c = 3 \times 10^{8}\mathrm{m/s}$.

**QUESTION ONE (30 MARKS) – COMPULSORY**

a) Define the following terms as used in optical electronics. **[3marks]**
   i. Laser
   ii. Refraction index
   iii. Attenuation in optical fibers

b) State two applications of lasers in the industry. **[2marks]**

c) With the aid of a diagram, explain the principle of operation of the Ruby Laser. **[5marks]**

d) Silica has an estimate fictive temperature of $1400\ \mathrm{K}$ with an isothermal compressibility of $7 \times 10^{-10}\mathrm{m^2\ N^{-1}}$. The refractive index and the photoelastic coefficient for silica are $1.46$ and $0.286$ respectively. Determine the theoretical attenuation in decibels per kilometre due to the fundamental Rayleigh scattering in silica at optical wavelengths of 0.63 and1.30 μm **[6 marks]**

e) You need to transmit data over an optical link of 100 km with fiber loss of 0.2 dB/km. The link has five splices with 0.05 dB loss per splice and two connectors with 0.2 dB per connector. The receiver sensitivity is 20 μW. Express the minimum transmitter power in both mW and dBm. **[6 marks]**

f) Consider an optical fiber of 50 μm diameter, core index $n_1 = 1.5$, and cladding index $n_1 = 1.49$ for operation at $\lambda = 1.31\mu m$. **[8 marks]**

i. What is the numerical aperture (NA) of this fiber?
ii. How many modes does this fiber support?
iii. What would be the pulse spread due to modal dispersion over a distance of 10 km?
iv. What would the maximum fiber diameter need to be for the fiber to operate with a single mode?

## QUESTION TWO [20 MARKS]

a) Identify and explain two advantages of Optical Fiber communication. **[4 marks]**

b) Laser radiation is characterized by certain properties, which are not present in other electromagnetic radiation. Identify and explain these properties. **[6 marks]**

c) A typical relative refractive index for an optical fiber designed for long distance transmission is 1%. Assuming that the concept of geometric optics hold for the fiber: **[4marks]**

i. Estimate the Numerical Aperture (NA) and the solid acceptance angle in air for the fiber when the fiber core index is 1.46.
ii. Calculate the critical angle at the core-cladding interface within the fiber.

d) Two step index fibers exhibit the following parameters: **[6 marks]**

i. A multimode fiber with a core refractive index of 1.5, a relative refractive index difference of 3% and an operating wavelength of 0.82μm.
ii. An 8 μm core diameter single-mode fiber with a core refractive index the same as (i), a relative refractive index difference of 0.3% and an operating wavelength of 1.55 μm.

Estimate the critical radius of curvature at which large bending losses occur in both cases.

## QUESTION THREE [20 MARKS]

a) Outline the two ways in which energy transfer to and from the atom can take place. **[2 marks]**

b) Explain the concept of intramodal dispersion in optical signal transmission. **[2 marks]**

c) The visible spectrum wavelength range is (0.4 - 0.7 [μm]) or (400-700 [nm]).
The wavelength of the violet light is the shortest, and the wavelength of the red light is the longest. Calculate: **[6 marks]**

i. The frequency range of the visible spectrum.
ii. The amount of the photon's energy associated with the violet light, compared to the photon energy of the red light and comment on the energy values.

d) For an optical communications system, the transmitter and receiver operate at $2.5\ \mathrm{Gb/sec}$ NRZ ($B_{NRZ}$) at a central wavelength of $1550\ \mathrm{nm}$, using a laser with a spectral linewidth of $\Delta\lambda = 0.05\mathrm{nm}$. The fiber has a dispersion parameter of $\mathrm{M} = -20\ \mathrm{ps/nm.km}$.
**[10 marks]**

i. Calculate the pulse spread per unit distance ($\mathrm{ps/km}$).
ii. What is the maximum length of fiber that allows the stated system bit rate?
iii. If the system were to operate at $10\ \mathrm{Gb/sec}$ NRZ, then what would be the required optical bandwidth $f_{3dB;optical}$ ? Hint: you do not need fiber length or $\Delta\lambda$ for this calculation.
iv. Given the optical bandwidth of part iii), then what would be the optical frequency spread in terms of $\Delta\lambda$? What would be the maximum fiber length?

**QUESTION FOUR [20 MARKS]**

a) With the aid of a diagram, explain the principle of operation of a typical Four-level Laser System. **[6 marks]**

b) Calculate the power density of radiation per unit area at a distance of $2$ meters, from an incandescent lamp rated $100\ \mathrm{W}$, compared to a Helium-Neon laser of $1\ \mathrm{mW}$ and comment on the results. The laser beam diameter at the laser output is $2\ \mathrm{mm}$, and its divergence is $1\ [\mathrm{m.rad}]$.
**[4 marks]**

c) A 1km fiber has a core and cladding indices of $n_1 = 1.48$ and $n_2 = 1.46$. The core diameter is $50\ \mu\mathrm{m}$. Find **[10 marks]**
i. The minimum angle that supports total internal reflection
ii. The time delay of an off-axis ray compared to a ray that propagate directly down the fiber and
iii. An estimate of the modal-dispersion-limited bandwidth
iv. Comment on the results obtained in this question.

**QUESTION FIVE [20 MARKS]**

a) Distinguish between spontaneous emission and stimulated emission as used in lasers, highlighting the key characteristics of each. **[6 marks]**

b) Explain Mie scattering in optical fiber and identify two methods of reducing it. **[3 marks]**

c) A multiple graded index fiber exhibits total pulse broadening of $0.1\ \mu s$ over a distance of 15 km. Estimate **[5 marks]**
i. the maximum possible bandwidth on the link assuming no intersymbol interference
ii. the pulse dispersion per unit length
iii. the bandwidth-length product for the fiber

d) When the mean optical power launched into an 8 km length of fiber is 120 μW, the mean optical power at the fiber output is 3 μW. **[6 marks]**

Determine:

i. the overall signal attenuation or loss in decibels through the fiber assuming there are no connectors or splices

ii. the signal attenuation per kilometer for the fiber

iii. the overall signal attenuation for a 10km optical link using the same fiber with splices at 1km intervals, each giving an attenuation of 1 dB.

iv. The numerical input/output power ratio in (iii)