B.Sc (HONS.) IN ECE, PART-III, SIXTH SEMESTER EXAMINATION, 2019
OPTICAL FIBER COMMUNICATION
Subject Code : ECE-311
Time – 3 hours
Full marks – 80

[N.B. The figures in the right margin indicate full marks. Answer any five questions.]

Temporary Chat

Q1 (a) [5 marks]

What is an optical fiber? Explain the principle of light transmission in an optical fiber.

Answer:

- **Definition:** An optical fiber is a cylindrical dielectric waveguide made of glass or plastic, used to transmit light signals over long distances.
- **Structure:** Core (higher refractive index), Cladding (lower refractive index), Protective coating.
- **Principle:** Transmission occurs by **Total Internal Reflection (TIR)**.
  - If light enters the core at an angle greater than the **critical angle**, it reflects completely at the core–cladding interface.
  - Thus, light is guided through the fiber with minimal loss.

Q1 (b) [2 marks]

Define refractive index and Snell's law.

Answer:

- **Refractive Index (n):**
  Ratio of the speed of light in vacuum (c) to the speed of light in a medium (v).

$$n = \frac{c}{v}$$

- **Snell's Law:**
  Relationship between incidence and refraction a. es:

Q1 (c) [5 marks]

Describe the basic block diagram of a fiber optic communication system.

Answer:
A basic system consists of:

1. **Transmitter:**
   - Converts electrical signal → optical signal.
   - Light sources: LED or Laser Diode.
2. **Optical Fiber Channel:**
   - Transmission medium (core + cladding).
   - Guides light using total internal reflection.
3. **Receiver:**
   - Converts optical signal back to electrical signal.
   - Uses photodetectors (PIN diode / APD).
4. **Regenerators/Amplifiers (optional):**
   - Strengthen weak signals for long-distance links.

Q1 (d) [4 marks]

Differentiate between Step Index Fiber and Graded Index Fiber.

Feature	Step Index Fiber	Graded Index Fiber
Refractive Index	Constant in the core, sudden step at cladding	Varies gradually from center to edge
Light Path	Zig-zag reflections	Smooth curved paths due to gradual bending
Dispersion	High modal dispersion	Reduced dispersion
Bandwidth	Low	Higher
Cost	Less expensive	More expensive

Q2 (a) [6 marks]

With figure derive the equation of acceptance angle of an optical fiber.

- When light enters an optical fiber, only those rays within a certain angle with the fiber axis can undergo **total internal reflection (TIR)** inside the core.
- This angle at the fiber entrance is called the **Acceptance Angle (θa)**.
- **Derivation:**
  - From Snell's law:

$$n_0 \sin \theta_a = n_1 \sin \theta_c$$

where n_0 = refractive index of air ≈ 1,

n_1 = refractive index of core,

θ_c = critical angle at core–cladding interface.

- Critical angle:

$$\sin \theta_c = \frac{n_2}{n_1}$$

where n_2 = cladding refractive index.

- Substituting:

$$\sin \theta_a = \sqrt{n_1^2 - n_2^2}$$

- **Numerical Aperture (NA):**

$$NA = \sin \theta_a = \sqrt{n_1^2 - n_2^2}$$

Thus, **Acceptance Angle** depends on refractive indices of core and cladding.

(Draw a simple diagram: fiber core, cladding, incident ray, acceptance cone, θa.)

Temporary Chat

Q2 (b) [4 marks]

An optical fiber has core index = 1.495, cladding index = 1.402. Determine:

(i) Critical incident angle

(ii) Critical propagation angle

(iii) Acceptance angle

(iv) Numerical aperture

Answer:

- Given:
  $n_1 = 1.495$, $n_2 = 1.402$.

(i) **Critical angle (θc):**

$$\sin\theta_c = \frac{n_2}{n_1} = \frac{1.402}{1.495} \approx 0.9377$$

$$\theta_c = \sin^{-1}(0.9377) \approx 69.5^\circ$$

(ii) **Critical propagation angle (θp):**

$$\theta_p = 90^\circ - \theta_c = 20.5^\circ$$

(iii) **Numerical Aperture (NA):**

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.495)^2 - (1.402)^2}$$

$$NA = \sqrt{2.235 - 1.965} = \sqrt{0.270} \approx 0.52$$

(iv) **Acceptance angle (θa):**

$$\theta_a = \sin^{-1}(NA) = \sin^{-1}(0.52) \approx 31.4^\circ$$

Q2 (c) [4 marks]

Temporary Chat

Differentiate between intermodal dispersion and intramodal dispersion.

Feature	Intermodal Dispersion	Intramodal Dispersion
Cause	Different propagation paths (modes) in multimode fiber	Wavelength dependence of material & waveguide
Fiber Type	Occurs only in multimode fibers	Occurs in both single-mode & multimode fibers
Effect	Pulse broadening due to different mode delays	Pulse spreading due to chromatic dispersion
Minimization	Use single-mode fiber or graded index fiber	Use narrow spectral width sources (lasers)

Ask ChatGPT

Q2 (d) [2 marks]

What is attenuation in an optical fiber?

Answer:

- Attenuation = loss of optical power as light travels through the fiber.
- Expressed in decibels per kilometer (dB/km).

$$\alpha = \frac{10}{L}\log_{10}\left(\frac{P_{in}}{P_{out}}\right) \quad (dB/km)$$

where P_{in} = input power, P_{out} = output power, L = fiber length.

Q3 (a) [6 marks]

What is a photodiode? Explain the principle of operation of a photodiode.

Definition:
A **photodiode** is a semiconductor **p–n / p–i–n / APD** junction operated typically in **reverse bias** to convert incident optical power into electrical current.

Operation principle:

- Incident photons ($h\nu \geq E_g$) are absorbed in the depletion/intrinsic region → generate **electron–hole pairs.**
- The reverse electric field **separates** carriers (electrons → n, holes → p) producing a **photocurrent** proportional to optical power.
- Total current: $I = I_D + I_P$ (dark + photo). Under proper bias $I_P \gg I_D$.
- **Responsivity:** $R = \dfrac{I_P}{P_{opt}} \approx \eta \dfrac{q}{h\nu}$ (A/W), where η = quantum efficiency.
- **Types:**
  - **PIN diode:** intrinsic layer widens depletion region → fast, low noise.
  - **APD:** high reverse bias gives **avalanche multiplication** (gain $M \sim 5\text{–}100$) for high sensitivity but more noise and higher bias.

Q3 (b) [4 marks]

Define dark current and explain the characteristics curve of photodiode.

Dark current (I_D): Reverse current that flows **in the absence of light** due to thermally generated carriers and surface leakage. It sets the noise floor and limits detectivity.

Characteristics curve (reverse I–V):

- At **zero light**, reverse current ≈ I_D and slowly increases with reverse bias.
- Under illumination, the I–V curve **shifts downward** by the photocurrent I_P; current is nearly **linear with optical power** in the reverse-bias region.
- **Saturation region:** For sufficient reverse bias, I_P is nearly constant (field fully sweeps carriers).
- For **APD**, current rises sharply near **breakdown voltage** V_{br} due to avalanche gain.

(Also note: higher temperature → larger I_D; larger area → larger I_D.)

Q3 (c) [8 marks]

What is an optical amplifier? Explain the principle of erbium-doped fiber amplifier (EDFA).

Optical amplifier: A device that **directly amplifies optical signals** without O-E-O conversion by providing **stimulated emission** gain in a suitable medium (e.g., doped fiber, semiconductor, Raman).

EDFA principle (key points):

- **Medium:** Silica fiber **doped with Er^{3+} ions** (erbium).
- **Pumping:** A laser at **980 nm** or **1480 nm** is coupled with the signal (typically **C-band 1530–1565 nm**, also L-band) using a **WDM coupler**.
- **Three-level system:**
  1. Pump excites Er^{3+} from ground $^4I_{15/2}$ to upper levels → fast non-radiative decay to metastable $^4I_{13/2}$.

$I_{13/2}$.

2. **Population inversion** builds up in ${}^4I_{13/2}$.
3. Signal photons at ~1550 nm trigger **stimulated emission** back to ${}^4I_{15/2}$, amplifying the signal along the doped fiber.

- **Components (typical line EDFA):**
  - Pump laser(s) + wavelength coupler
  - Er-doped fiber (gain medium)
  - **Isolators** (prevent lasing/feedback)
  - **Gain-flattening filter** (equalize WDM channels)
  - **Monitors**/taps, sometimes **ASE filters**
- **Performance:** High gain (20–40 dB), high output power (> +17 dBm), low noise figure (≈4–6 dB), broad flat gain over C/L bands; ideal for long-haul **WDM** links.
- **Noise:** Generates **amplified spontaneous emission (ASE)** which must be managed with filters and proper gain.

Q4 (a) [8 marks]

Describe the phenomenon of modal noise in optical fiber and suggest how it may be avoided.

Modal noise:

- Occurs in **multimode fibers** when coherent light sources (e.g., lasers) excite several modes.
- Interference between these modes produces a **speckle pattern** at the output.
- If the fiber is disturbed (vibration, connector movement, bending), the speckle pattern changes randomly, causing **intensity fluctuations** → noise in the received signal.
- More significant in **narrowband coherent systems** (e.g., laser sources) than with LEDs (broadband, incoherent).

Avoidance techniques:

1. Use **single-mode fibers** (only one mode, no intermodal interference).
2. Use **broadband sources (LEDs)** instead of highly coherent lasers.
3. Employ **mode scramblers** or mode mixers to average modal distribution.
4. Ensure **good connectors and splicing** to minimize mode selectivity.
5. Use **shorter multimode fiber lengths** in coherent systems.

Q4 (b) [4 marks]

Write down the difference between stimulated emission and spontaneous emission.

Feature	Spontaneous Emission	Stimulated Emission
Cause	Atom decays randomly from excited state	Triggered by incident photon
Phase & Direction	Random in phase, direction, and polarization	Same phase, frequency, direction, and polarization
Coherence	Incoherent light produced (e.g., LED)	Coherent light (basis of LASER operation)
Dependence	Depends only on lifetime of excited state	Depends on photon flux + population inversion

Q4 (c) [4 marks]

How attenuation is related to quality of fiber?

Answer:

- Attenuation = measure of optical power loss per unit length of fiber (dB/km).
- **Lower attenuation → better quality fiber** because more signal power reaches the receiver without amplifiers.
- High attenuation means:
  - More **repeaters/amplifiers** required.
  - Lower **signal-to-noise ratio (SNR)**.
  - Reduced **data rate and transmission distance.**
- Modern high-quality silica fibers have attenuation as low as **0.2 dB/km at 1550 nm** (near optimum wavelength window).

Q5 (a) [6 marks]

What is population inversion? Describe basic operation of four-level LASER light.

Population Inversion:

- Condition where **number of atoms in excited state (N_2) > number in ground state (N_1).**
- Essential for **stimulated emission** to dominate over absorption, allowing light amplification.

Four-level Laser operation:

1. **Pump transition:** Atoms excited from ground state (E_0) to high energy level (E_3) using optical/electrical pumping.
2. **Fast decay:** Atoms quickly relax (non-radiative) to a lower metastable state (E_2).
3. **Stimulated emission:** Atoms at E_2 release photons when stimulated by incident photons, falling to E_1.
4. **Rapid decay:** Atoms at E_1 quickly decay to ground state E_0, preventing re-absorption.

Advantage:

- Easier to achieve population inversion than in 3-level lasers.
- Produces continuous, efficient, coherent output (e.g., Nd:YAG laser).

Q5 (b) [6 marks]

With block diagram explain how repeater works.

Optical Repeater:

- Device used in long-distance fiber links to restore weakened signals.
- Functions: **Receive → Reshape → Regenerate → Retransmit.**

Block diagram:

1. **Optical Receiver (Photodiode):** Converts optical signal → electrical.
2. **Regenerator/Decision Circuit:** Removes noise, reshapes pulse (digital logic).
3. **Transmitter (Laser/LED):** Converts electrical back to optical.
4. **Output:** Clean optical signal launched into next fiber section.

Use: Extends distance by compensating for attenuation and dispersion.

Q5 (b) [6 marks]

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Q5 (c) [4 marks]

Optical power of 1 mW is launched into an optical fiber of length 100 m. If the power emerging from the other end is 0.03 mW, calculate the fiber attenuation.

Given:

- $P_{in} = 1\,\text{mW}$,
- $P_{out} = 0.03\,\text{mW}$,
- $L = 100\,\text{m} = 0.1\,\text{km}$.

Formula:

$$\alpha = \frac{10}{L}\log_{10}\left(\frac{P_{in}}{P_{out}}\right) \quad (\text{dB/km})$$

Calculation:

$$\alpha = \frac{10}{0.1}\log_{10}\left(\frac{1}{0.03}\right)$$

$$\alpha = 100 \times \log_{10}(33.33) \approx 100 \times 1.52 = 152\,\text{dB/km}$$

Answer: Attenuation of fiber = **152 dB/km**.

Q6 (c) [6 marks]

What is fiber distributed data interface (FDDI)? Explain its architecture layers.

FDDI:

- Stands for **Fiber Distributed Data Interface**.
- A high-speed (100 Mbps) **LAN protocol** standard using optical fiber.
- Typically uses a **dual-ring topology** (primary + secondary ring for backup).
- Provides **high reliability** and is used for campus networks and backbone.

Architecture layers (similar to OSI model):

1. **Physical Layer (PHY):**
   - Defines optical fiber, encoding (4B/5B), transmission at 100 Mbps.
2. **Physical Medium Dependent (PMD):**
   - Details fiber type (multimode/single-mode), connectors, optical power levels.
3. **Data Link Layer:** Divided into two sublayers:
   - **Media Access Control (MAC):** Implements **Token Passing** protocol for channel access.
   - **Logical Link Control (LLC):** Provides interface to upper layers, manages addressing and flow.

Features: High speed, fault tolerance (dual ring), supports up to 500 stations, distance up to 200 km.

Temporary Chat

Q6 (a) [6 marks]

What are modes in an optical fiber? Calculate the number of modes for a multimode step-index fiber if core diameter $d = 62.5\,\mu m$, numerical aperture $NA = 0.275$, and operating wavelength $\lambda = 1300\,nm$.

Modes:

- Modes are the possible paths (field distributions) that light rays can take while propagating inside the fiber, satisfying boundary conditions.
- **Single-mode fiber:** supports only one mode (fundamental).
- **Multimode fiber:** supports multiple modes due to larger core diameter.

Formula (V-number):

$$V = \frac{2\pi a}{\lambda} \cdot NA$$

where $a = \frac{d}{2} = \frac{62.5}{2} = 31.25\,\mu m = 31.25 \times 10^{-6}\,m$.

$$V = \frac{2\pi(31.25 \times 10^{-6})}{1300 \times 10^{-9}} \times 0.275$$

$$V = \frac{2\pi \cdot 31.25}{1300} \times 0.275 \times 10^{3}$$

$$V \approx 41.6$$

Number of modes (for step-index multimode):

$$M \approx \frac{V^2}{2} = \frac{(41.6)^2}{2} \approx \frac{1730}{2} \approx 865$$

Answer: The fiber supports approximately **865 modes**.

Q6 (b) [6 marks]

What is the role of Fiber Bragg Grating (FBG) in WDM? With figure explain its operation.

Role of FBG in WDM:

- FBG is an optical filter formed by periodic variation of refractive index in the fiber core.
- It reflects a specific wavelength (Bragg wavelength λ_B) and transmits others.
- In WDM systems, FBGs are used for:
  - **Wavelength selection** (drop or add channels).
  - **Dispersion compensation.**
  - **Channel equalization.**

Bragg condition:

$$\lambda_B = 2n_{eff}\Lambda$$

where n_{eff} = effective refractive index, Λ = grating period.

Operation (with figure):

- Multiple WDM channels enter the FBG.
- One channel (at λ_B) is **reflected back**, others pass through.
- By tuning grating period, specific channels can be separated.

(Figure: Input fiber with grating → one λ reflected, rest transmitted.)