B.Sc. (HONS.) IN ECE, PART-III, SIXTH SEMESTER EXAMINATION, 2020

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.]

1. **(a) What is an optical fiber? What are the major two problems encountered in the early development of optical fibers for practical use in communications systems?**
   Marks: 3
   Answer:
   Optical fiber is a thin strand of glass or plastic used to transmit light signals for communication. The major problems faced during its early development were:
   - **Loss of signal** due to attenuation, especially in long-distance transmissions.
   - **Difficulty in producing high-quality fibers** with low dispersion and minimal signal loss.
2. **(b) Describe the structure of an optical fiber.**
   Marks: 4
   Answer:
   The structure of an optical fiber consists of three main parts:
   - **Core**: The central part made of glass or plastic, through which the light signals travel.
   - **Cladding**: Surrounds the core, also made of glass or plastic but with a lower refractive index than the core.
   - **Jacket**: The outer protective layer that prote the fiber from physical damage.

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

Marks: 5

Answer:

The basic block diagram of a fiber optic communication system consists of:

- **Transmitter**: Converts electrical signals to optical signals (usually via a LED or laser).
- **Optical Fiber**: A medium to carry the light signals.
- **Receiver**: Converts optical signals back into electrical signals.
- **Amplifiers (if needed)**: Amplify the signal if it's degraded over long distances.

(d) Write some advantages of fiber optic communications over other types of communication technologies.

Marks: 4

Answer:

- **High bandwidth**: Optical fibers can carry a large amount of data at high speeds.
- **Low signal loss**: Unlike copper cables, optical fibers experience very little attenuation, allowing for long-distance communication.
- **Immunity to electromagnetic interference**: Optical fibers are not affected by radio frequency interference or electrical noise.
- **Lightweight and flexible**: Easier to handle and install, particularly for high-capacity systems.

2. (a) What do you mean by numerical aperture? Prove that, $N.A. = \sqrt{n_1^2 - n_2^2} = \sin\theta$

Marks: 4

Answer:

Numerical aperture (N.A.) refers to the ability of an optical fiber to gather light. It is defined as:

$$N.A. = \sqrt{n_1^2 - n_2^2}$$

where n_1 is the refractive index of the core, and n_2 is the refractive index of the cladding.

The relationship $\sin\theta$ (where θ is the angle of acceptance) shows the maximum angle at which light can be accepted by the fiber and still be guided.

(b) The refractive index of core of a plastic optical fiber is $n_1 = 1.495$ and the refractive index of the cladding is $n_2 = 1.402$. Under what condition will light be trapped inside the core?

Marks: 4

Answer:

Light will be trapped inside the core if the angle of incidence at the core-cladding interface is greater than the critical angle, defined by:

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

For $n_1 = 1.495$ and $n_2 = 1.402$, calculate the critical angle θ_c as:

$$\theta_c = \sin^{-1}\left(\frac{1.402}{1.495}\right)$$

This will give the condition for total internal reflection, ensuring light stays in the core.

(c) What is V-number? Calculate the number of modes for a graded index fiber if its core diameter is $d = 62.5\ \mu m$, its numerical aperture $N.A. = 0.275$ and its operating wavelength is 1300nm.

Marks: 6

Answer:

The V-number (normalized frequency) is given by:

$$V = \frac{2\pi a}{\lambda} N.A.$$

where $a = \frac{d}{2} = 31.25\ \mu m$ is the core radius, and $\lambda = 1300\ \mathrm{nm}$.

Substituting the given values:

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

Calculate the number of modes:

$$M = \frac{V^2}{2}$$

3. (a) What is attenuation? Show that, $\alpha = \frac{10}{L} \log \frac{P_{in}}{P_{out}}$

Marks: 2

Answer:

Attenuation is the reduction in signal strength as light travels through the fiber. It is expressed as:

$$\alpha = \frac{10}{L} \log \frac{P_{in}}{P_{out}}$$

where P_{in} is the input power, P_{out} is the output power, and L is the length of the fiber.

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4. (b) How attenuation is related to the quality of fiber?

Marks: 3

Answer:

Attenuation directly affects the quality of fiber communication. A higher attenuation leads to signal degradation over longer distances, necessitating more frequent signal amplification or regeneration, which reduces the efficiency and reliability of the communication system.

(c) What is optical amplifier? Explain the principle of erbium doped fiber amplifier (EFDA).

Marks: 4

Answer:

An optical amplifier is a device that amplifies optical signals without converting them to electrical signals. The **Erbium-doped fiber amplifier (EDFA)** works by using a fiber doped with erbium ions (Er3+). When a pump laser injects energy into the fiber, the erbium ions are excited, and when the signal passes through, the ions release energy to amplify the signal.

4. (a) What are the different sources of light in optical fiber communication systems?

Marks: 2

Answer:

In optical fiber communication, light is generated by the following sources:

1. **LEDs (Light Emitting Diodes):** LEDs are used as light sources in short-distance communication due to their low cost, simplicity, and ease of use. They emit incoherent light and are typically used in multimode fibers.
2. **Laser Diodes:** These are commonly used for long-distance communications. Laser diodes emit coherent light, allowing for precise control of the light beam. They provide higher efficiency and faster data rates than LEDs, making them suitable for single-mode fibers.

4. (b) Explain how semiconductor LASER works.

Marks: 4

Answer:

A **semiconductor LASER (Light Amplification by Stimulated Emission of Radiation)** works based on the principles of **quantum mechanics**. Here's how it works:

1. **Electron Injection**: When a current is passed through a semiconductor material (like gallium arsenide), electrons are injected into the **conduction band**, while **holes** (positive charge carriers) are created in the **valence band**.
2. **Recombination**: These electrons and holes recombine in the active region of the laser, releasing energy in the form of photons.
3. **Stimulated Emission:** These photons can stimulate other excited electrons to release more photons, creating a coherent light beam. This process is known as **stimulated emission**.
4. **Amplification:** The emitted photons are reflected back and forth between two mirrors at either end of the semiconductor, resulting in amplification of the light.

The **output of the LASER** is coherent (all photons are in phase) and monochromatic (single wavelength), which is ideal for long-distance fiber optic communication.

4. (c) How an LED can be coupled to an optical fiber? Describe briefly.

Marks: 3

Answer:

To couple an **LED (Light Emitting Diode)** to an optical fiber, the following steps are typically followed:

1. **Alignment:** The LED is positioned very close to the core of the optical fiber, ensuring that the light emitted from the LED is focused into the fiber core. This is done by aligning the LED to the fiber's axis.
2. **Optical Lens:** Sometimes, an **optical lens** is used between the LED and the fiber to focus the light more efficiently into the fiber core.
3. **Index Matching Gel:** To minimize reflection losses and improve coupling efficiency, **index-matching gel** (with a refractive index between that of the LED and fiber) can be applied to the fiber tip. This ensures smooth transmission of light from the LED into the fiber.
4. **Mode Matching:** The LED's emission should match the fiber's mode structure to achieve efficient coupling. For multimode fibers, the light output of the LED typically matches the fiber modes, making coupling easier.

4. (d) Write down the difference between LED and LASER.

Marks: 2

Answer:

Feature	LED (Light Emitting Diode)	Laser (Light Amplification by Stimulated Emission of Radiation)
Emission Type	Incoherent light (light waves are not in phase)	Coherent light (light waves are in phase)
Spectral Width	Broad spectral output (multiple wavelengths)	Narrow spectral output (single wavelength)
Efficiency	Lower efficiency (less power converted to light)	Higher efficiency (more power converted to light)
Cost	Less expensive	More expensive
Application	Short-distance communication, low-speed systems	Long-distance communication, high-speed systems, precise applications
Power Output	Lower output power	Higher output power

5. (a) What is modulation technique? Explain briefly Pulse Code Modulation (PCM).

Marks: 5

Answer:

Modulation is the process of varying a carrier signal to transmit information. **Pulse Code Modulation (PCM)** is a digital modulation technique used for encoding analog signals into digital form.

How PCM works:

1. **Sampling:** The analog signal is sampled at regular intervals to convert it into a discrete-time signal. This is typically done at twice the highest frequency of the signal (Nyquist criterion).
2. **Quantization:** Each sample is then quantized, meaning that its amplitude is approximated to the nearest value from a set of predefined levels. This step introduces a quantization error (difference between the actual signal and its quantized value).
3. **Encoding:** The quantized samples are encoded into binary code (a sequence of 0s and 1s). This sequence is transmitted to the receiver.
4. **Decoding:** The receiver decodes the binary sequence back into the original signal, closely resembling the analog signal.

PCM is widely used in **telecommunication systems** and **audio recording** (e.g., CDs, digital telephony).

5. (b) Why multiplexing is necessary? Write a short note on DWDM.

Marks: 5

Answer:

Multiplexing is a technique used to combine multiple signals into a single transmission medium, allowing for efficient use of available bandwidth. This is especially important for **fiber optic communication**, where a large amount of data needs to be transmitted over a single fiber.

Reasons for Multiplexing:

1. **Maximizing Bandwidth Utilization:** Multiplexing allows several signals to be transmitted simultaneously without interference, making better use of the available bandwidth.
2. **Cost-Effectiveness:** By transmitting multiple signals over a single fiber, the cost of infrastructure is reduced, as fewer fibers and equipment are needed.
3. **Efficient Use of Resources:** Multiple users or data streams can share the same medium, enhancing system capacity.

Dense Wavelength Division Multiplexing (DWDM) is a form of multiplexing where **different wavelengths (or channels)** of light are used to transmit multiple signals simultaneously through a single optical fiber.

- DWDM enables the transmission of **hundreds of channels** with high data rates (up to 100 Gbps per channel), making it ideal for **long-distance and high-capacity transmission.**
- By using various wavelengths, DWDM efficiently increases the **capacity** of fiber-optic systems without requiring additional fibers.

5. (c) What is photodiode? Explain the principle of PIN photodiode.

Marks: 6

Answer:

A **photodiode** is a semiconductor device that converts **light** into an **electrical current.** When light strikes the photodiode, it generates **electron-hole pairs**, and the movement of these charge carriers creates a photocurrent.

The **PIN photodiode** is a specific type of photodiode that consists of three layers:

1. **P-layer (positive):** The region with an excess of holes.
2. **I-layer (intrinsic):** A pure, undoped region between the P and N layers.
3. **N-layer (negative):** The region with an excess of electrons.

Principle of Operation:

- When light strikes the **intrinsic region (I-layer)**, it generates **electron-hole pairs.**
- A **reverse bias** is applied to the photodiode, causing the **electrons** to move towards the **N-layer** and the **holes** to move towards the **P-layer**, resulting in an electrical current proportional to the intensity of the incoming light.
- The **intrinsic layer** plays a crucial role in increasing **the speed** and **efficiency** of the photodiode by allowing for fast carrier recombination and reducing the junction capacitance.

6. (a) What is SONET? Draw and explain a simple network with SONET equipment.

Marks: 5
Answer:
SONET (Synchronous Optical Networking) is a standardized digital communication protocol used for transmitting high-speed data over fiber optic networks. It defines how data is multiplexed and transmitted in the form of **optical carriers (OC)**.

SONET Network:
A simple SONET network consists of the following equipment:

- **Terminal Equipment (TE):** This equipment interfaces with external data sources (e.g., computers, switches) and converts data into the SONET format.
- **Add/Drop Multiplexer (ADM):** ADM is used to add or drop specific signals from a SONET stream. It allows for selective access to channels without affecting the rest of the data.
- **Optical Line Terminals (OLT):** These devices manage data transmission and reception at the edges of the SONET network.
- **Optical Line Amplifiers (OLAs):** These are used to boost the signal strength over long distances.

6. (b) Describe wavelength division multiplexing briefly.

Marks: 4
Answer:
Wavelength Division Multiplexing (WDM) is a technique used in optical fiber communications to combine multiple optical signals, each at a different wavelength (or channel), into a single fiber. This allows for multiple data streams to be transmitted simultaneously over a single optical fiber, greatly increasing the fiber's capacity.

Types of WDM:

1. **Coarse Wavelength Division Multiplexing (CWDM):** Uses a wider spacing between channels, typically up to 18 channels, and is used for short to medium-distance communications.
2. **Dense Wavelength Division Multiplexing (DWDM):** Uses a smaller spacing between channels, allowing for hundreds of channels (with data rates of up to 100 Gbps or more per channel). It is used for long-distance, high-capacity communication systems.

Working Principle:

- Different data streams are assigned to different wavelengths (or optical carriers).
- A **multiplexer** combines the signals and sends them over a single fiber.
- At the receiver end, a **demultiplexer** separates the signals based on their wavelengths, and each signal is processed independently.

WDM is widely used in modern optical networks, allowing for efficient and high-capacity communication.

6. (c) Write short note on polarization mode dispersion.

Marks: 3
Answer:
Polarization Mode Dispersion (PMD) is a phenomenon in optical fibers that causes the broadening of light pulses as they travel along the fiber, particularly over long distances. It occurs due to the birefringence in the fiber, which causes the two polarization modes of light (horizontal and vertical) to travel at slightly different speeds.

Cause of PMD:

- **Manufacturing imperfections** in the fiber lead to slight asymmetries in the core, causing the two polarization modes to experience different refractive indices.
- The difference in speed causes the pulse to spread out over time, leading to signal distortion.

Impact of PMD:

- PMD causes **pulse broadening**, which leads to **inter-symbol interference** (ISI), reducing the quality of the transmitted signal.
- PMD is a significant issue in high-speed, long-distance communication systems and needs to be managed by using **polarization-maintaining fibers** or **compensating techniques**.

6. (d) Compare between LED and laser diode.

Marks: 3
Answer:

Feature	LED (Light Emitting Diode)	Laser Diode (LD)
Emission Type	Incoherent light (light waves are not in phase)	Coherent light (light waves are in phase)
Spectral Width	Broad spectral output (multiple wavelengths)	Narrow spectral output (single wavelength)
Efficiency	Lower efficiency (less power converted to light)	Higher efficiency (more power converted to light)
Application	Short-distance communication, low-speed systems	Long-distance communication, high-speed systems
Cost	Less expensive	More expensive
Power Output	Lower output power	Higher output power

7. Write short notes (any four):

(a) Optical Switch
Marks: 3
Answer:
An **optical switch** is a device used in optical networks to route optical signals from one fiber to another. It operates without converting the optical signal to an electrical signal, providing high-speed switching without significant signal degradation. Optical switches are used in network configurations like **optical cross-connects (OXCs)** to manage traffic and reroute signals based on network demands.

Types of Optical Switches:

- **Mechanical optical switches:** Use movable mirrors or prisms to redirect the signal.
- **Electro-optic switches:** Use materials that change their refractive index in response to an electric field to control the signal path.
- **Acousto-optic switches:** Use sound waves to modulate light signals.

(b) Optical Connector
Marks: 3
Answer:
An **optical connector** is used to join two optical fibers together, ensuring minimal signal loss during the connection. It allows for the alignment of the fiber cores so that the optical signal can pass from one fiber to the other with minimal attenuation.

Types of Optical Connectors:

- **SC (Subscriber Connector):** A push-pull type connector commonly used in data and telecom applications.
- **LC (Lucent Connector):** A smaller form factor connector, often used in high-density applications.
- **FC (Ferrule Connector):** A connector with a metal ferrule used for high-precision applications.

(c) Splices
Marks: 3
Answer:
Splicing refers to the process of joining two optical fibers together to create a continuous optical path. There are two main types of fiber splicing:

1. **Fusion Splicing:** This involves heating the fiber ends to fuse them together, ensuring low loss and high precision. It is commonly used in long-distance applications.
2. **Mechanical Splicing:** This involves aligning the fibers and using an adhesive or a mechanical fixture to hold them in place. It is easier but results in higher loss compared to fusion splicing.

(d) Optical Repeater
Marks: 3
Answer:
An **optical repeater** is a device used in optical communication systems to amplify or regenerate weak optical signals that have attenuated over long distances. Since optical signals degrade due to **attenuation** and **dispersion**, optical repeaters are used to maintain signal integrity over long stretches of fiber.

Types of Optical Repeaters:

1. **Amplifying Repeaters**: Use optical amplifiers like **erbium-doped fiber amplifiers (EDFA)** to boost signal strength without converting it to an electrical signal.
2. **Regenerating Repeaters**: Convert the optical signal to electrical form, process it, and then convert it back to optical form.

(e) FDDI (Fiber Distributed Data Interface)
Marks: 3
Answer:
FDDI is a set of ANSI standards for data transmission over fiber optic networks. It was designed for **high-speed LANs** and operates at speeds of up to **100 Mbps**.

Key Features:

- FDDI uses a **dual ring topology**, where data can travel in either direction, ensuring redundancy in case of fiber breaks.
- It is primarily used for backbone connections in wide-area networks (WANs).
- FDDI supports both **single-mode** and **multimode** fiber optics.

(f) Skew Rays
Marks: 3
Answer:
Skew rays are light rays in an optical fiber that do not propagate along the fiber's principal axes. These rays are **not confined** to the core and **do not follow the normal mode of propagation.** Skew rays can cause additional dispersion, increasing the distortion of the transmitted signal. They are primarily a concern in **multimode fibers**, where different paths of light rays cause variations in arrival times.