UNIT 4: Optical Fiber Communication

Syllabus:- **14 marks**

Introduction; Need for OFC, Block diagram of OFC, Fiber optic cables, Light propagation through fiber, Expression for NA (no derivation), Types of Light sources and Detectors, Losses in OFC, Advantages and disadvantages of OFC over metallic cables.

Introduction:-

One of the main limitations of communication systems is their restricted information carrying capabilities. In more specific terms what that means is that the communications medium can carry only so many messages. And, this information carrying capacity is directly proportional to the bandwidth of the communications channel. To increase the information carrying capacity the bandwidth of the channel must be increased, which can be archived by increasing the carrier frequency.

One way to expand communications capability further is to use light as the transmission medium. Instead of using an electrical signal traveling over a cable or electromagnetic waves travelling through space, the information is put on a light beam and transmitted through a special cable.

This type of communication where information is transmitted in the form of light is called as Fiber Optic communication.

Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. Fiber is preferred over electrical cabling when high bandwidth, long distance, or immunity to electromagnetic interference is required.

Optical fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals.

Advantages of FOC:-

Some of the innumerable benefits of optical fiber communication system are:

- Immense bandwidth to utilize
- *Greater information capacity:*
- Total electrical isolation in the transmission medium
- Very low transmission loss
- Small size and light weight
- High signal security
- Immunity to interference and crosstalk
- Very low power consumption and wide scope of system expansion etc.

Drawbacks of FOC:-

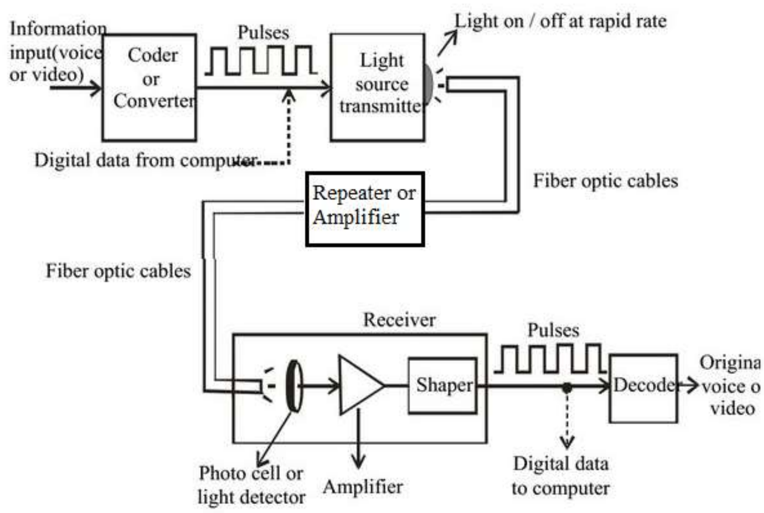
- Interfacing cost is high:
- Physical Strength of cable is less :
- Specialized tools, equipment and trained people is required:

Applications of FOC:-

Due to its variety of advantages optical fiber communication system has a wide range of application in different fields such as

- Public network field which includes trunk networks, junction networks, local access networks, submerged systems, synchronous systems etc.
- Field of military applications
- Civil, consumer and industrial applications.
- Field of computers which is the center of research right now.

Block diagram of OFC:-



The components of typical fiber optic communications systems are illustrated in the figure. The information signal to be transmitted may be voice, video or computer data.

Coder or converter: The first step is to convert the information into a form compatible with the communications medium. This is usually done by converting continuous analog signals into a series of digital pulses. An analog to Digital (A/D) converter is used for this purpose. Computer data is already in digital form. These pulses are then used to flash a powerful light source ON and OFF very rapidly.

Light source transmitter: the light source is usually a Light Emitting Diode (LED) or LASER light. This is a semiconductor that converts electrical energy into light energy. It puts out a low intensity red light beam. Other colors are also used. Infra-red beams are also used in transmission.

Fiber optic cable: Light from the source is fed into the fiber optic cable (FOC), which guides the light to propagate through. Light travel through the FOC and reach the other end by a phenomenon called Total Internal Reflection (TIR). This FOC is also called as light pipe.

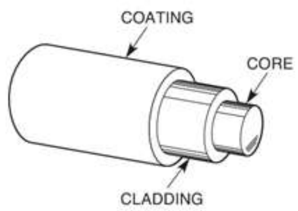
Repeater or amplifier: In very long distance transmission systems, repeater units are placed along the way. Since the light is gradually attenuated when it travels over long distances, at some point it may be too weak to be received reliably. To overcome this problem, special relay stations are used to pick up the light beam and convert it back into electrical pulses that are amplified, and then retransmit the pulses on another light beam.

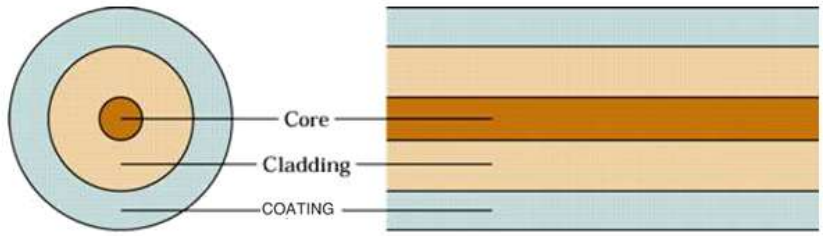
Receiver: at the receiving end, a light sensitive device known as a photo cell or photo detector is used to detect the light pulses. This photo cell or photo detector converts the light pulses into an electrical signal.

Amplifier and wave shaper: the received electrical pulses are amplified and reshaped back into a digital form. They are fed to a decoder.

Decoder: the reshaped digital pulses are fed to a decoder, which convert these pulses into original voice or video signal. Decoder is nothing but a digital to Analog (D/A) converter.

Fiber optic cables:-





A fiber optic cable is essentially a light pipe. An optical fiber is essentially a waveguide for light. It is not really a hollow tube carrying light, but it is long thin strand of glass or plastic fiber. Most fiber cables have a circular cross section with a diameter of only a function of an inch.

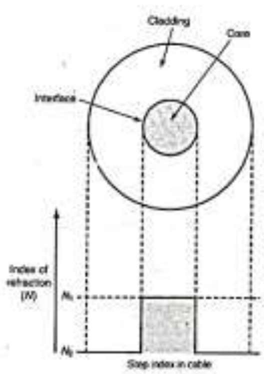
The portion of a fiber optic cable that carries the light is made from glass or plastic. An optical fiber consists of two parts, the inner cylindrical material called the core. This core is surrounded by a concentric cylinder called cladding; this is also made of the same material as the core but with a smaller refractive index. The **index of refraction** of the cladding is less than that of the core, causing rays of light leaving the core to be refracted back into the core. The cladding has to be protected against chemical reaction with the surroundings and also against crushing and abrasion. To ensure this, the cladding is enclosed in a jacket made of polyurethane.

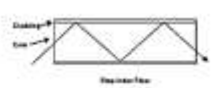
Classification of FOC:-

Based on the variation of refractive index, FOC can be classified into two types as

- Step index fiber
- Graded index fiber

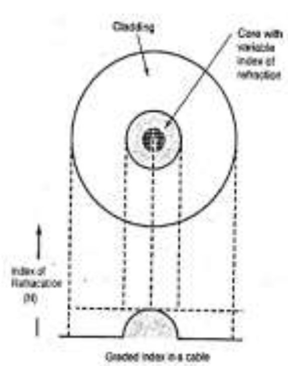
Step index fiber:-

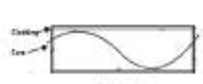




Step index refers to the fact that there is a sharply defined step in the refractive index at the core and cladding interface. In this type of fiber, the core has one constant refractive index (η_1) and the cladding has another constant refractive index (η_2). Where the two come together, there is a distinct step as shown in figure below.

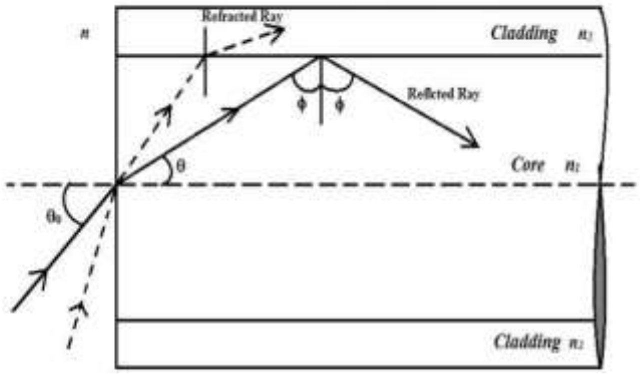
Graded index fiber:-





In this type of cable, the refractive index is not constant. Instead the refractive index varies smoothly and continuously over the diameter of the core as shown in figure. As we get closer to the center of the core, the refractive index gradually increases, reaching the peak at the center and then declining as the outer edge of the core is reached. The refractive index of the cladding is constant.

Light propagation through fiber:-



We know that, an optical fiber is a solid cylindrical glass rod called the core, through which light in the form of optical signals propagates. This rod is surrounded by another coaxial cylindrical shell made of glass of lower refractive index called the cladding. This basic arrangement that guides light over long distances is shown in figure

The light energy in the form of optical signals propagates inside the core cladding arrangement and throughout the length of the fiber by a phenomenon called the Total Internal Reflection (TIR) of light.

Total internal reflection at the fiber wall can occur if the following two conditions are satisfied.

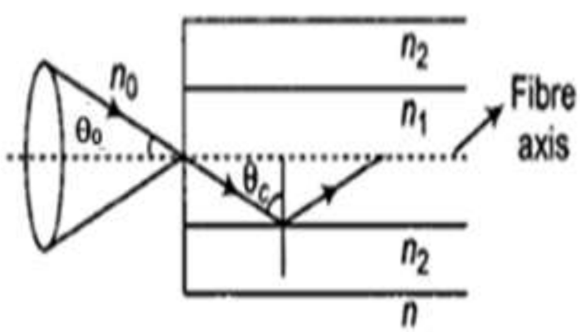
- The glass inside the fiber core must have a slightly higher refractive index (η_1) than the refractive index η_2 of the cladding
- The light must have an angle of incidence(ϕ) greater than a critical angle (ϕ_c) which is defined as

$$\mathbf{Sin}\ (\phi_c) = \frac{\eta 2}{\eta 1}$$

By multiple total internal reflections at the core-cladding interface the light propagates throughout the fiber over very long distances with low attenuation.

No matter what the angle of incidence of the light is, any light that enters the fiber from the side does not propagate along the fiber. The only option thus available with us is to launch the light through the tip of the fiber. That is, in order to guide light along the fiber, the light must be incident from the tip of the optical fiber. Equivalently, if there was propagation of light through the fiber, no light would emerge from the sides of the fiber.

Maximum Acceptance Angle (θ_{0max}): Acceptance angle is the maximum angle to the fiber axis at which the light may enter into the fiber optic cable and propagate along the cable.



η_1, η_2 = Refractive indices of core and cladding respectively

If angle of incidence to the fiber is greater than θ_0, then total internal reflection will not take place in optical fiber and some information will be lost.

$$\theta_{0max} = \sin^{-1}(NA)$$

$$\theta_{0max} = \sin^{-1}\sqrt{\eta_1^2 - \eta_2^2}$$

Numerical Aperture (NA): It is a measure of light collecting ability of fiber. It establishes the relationship between acceptance angle and refractive indexes of different medium involved.

$$NA = \eta_0 \sin\theta_{0max} = \sqrt{\eta_1^2 - \eta_2^2}$$

$NA = \eta_1\sqrt{2\Delta}$ where Δ is Relative Refractive Index Difference $\Delta = 1 - \frac{\eta 2}{\eta 1}$

Light sources:-

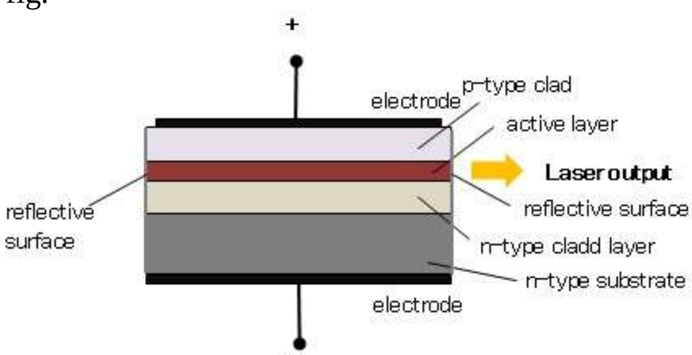
Light sources for fiber optics act as light transmitter and must meet certain requirements if they are to be acceptable for the purpose.

- The light produced by them should be monochromatic
- The light source should have high-output intensity
- The devices should be small and easily coupled
- They must be relatively inexpensive to manufacture.

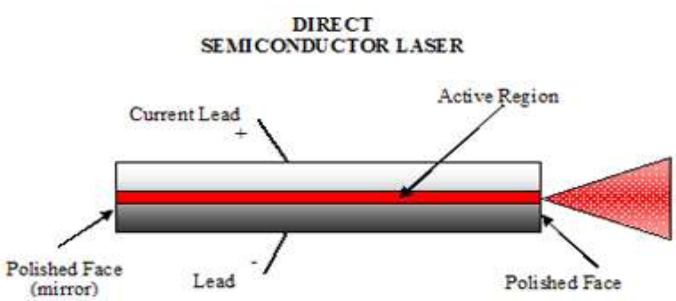
Light Emitting Diode (LED) and semiconductor LASERs are extensively used as light sources in fiber optic communication systems.

LASER:-

The term LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. It is similar to a LED in that when it is forward biased, current flows causing electrons to combine with hole. As the electrons fall into the holes, they release photons or light energy. This light is coherent light meaning that it consists of a single wavelength. The laser diodes are made from Aluminum Gallium Arsenide (AlGaAs) and Gallium Arsenide (GaAs). The basic structure of a laser diode is as shown in fig.



A PN junction is formed by the above two mentioned materials. The length of the PN junction has an exact relationship with the wavelength of the light to be emitted. There is a highly reflective surface at one end of the junction and a partially reflective surface at the other end. External leads provide the anode and cathode connections.



<u>*Operation:*</u> The PN junction is forward biased by an external voltage source. As electrons move across the junction, they fall in the holes thereby releasing photons. A released photon can strike an atom thereby releasing another photon. As the forward current is increased, more electrons enter the depletion region and cause more photons to be released. Some of these photons strike the reflective surface perpendicular. These reflected photons move along within the depletion region, striking atoms and releasing additional photons. This back-and –forth movement of photons increases as the generation of photons (snowballs) until very strong beam of laser light is formed by the photons that pass through the partially reflective surface at the end of the PN junction as shown in the figure.

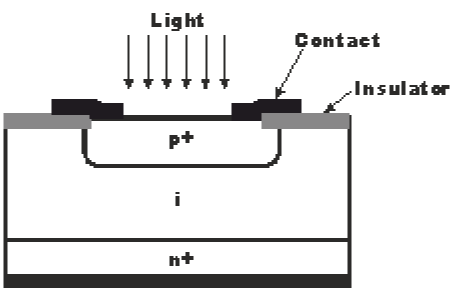
Optical receivers (Light Detectors):-

The basic optical receiver converts the modulated light coming from the optical fiber back into a replica of the original signal applied to the transmitter. The receiver part of the optical communication system is relatively simple. It consists of a detector that will sense the light pulses and convert them into an electrical signal. This signal is then amplified and shaped into the original serial digital data. The most critical component is the light detector.

Light detector is usually a photodiode of either the PIN or the Avalanche type. Since the amount of light that exists in a fiber is quite small, optical receivers usually employ high gain internal amplifiers. Photo diodes usually have a large sensitive detecting area that can be several hundred microns.

PIN diode:-

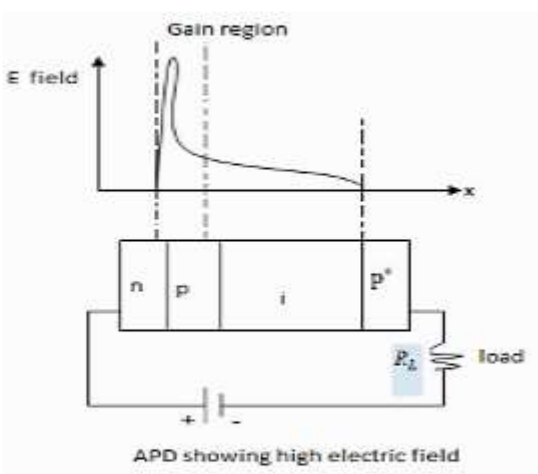
This is a silicon PN junction diode that is sensitive to light. This diode is normally reverse biased. The only current that flows through it is an extremely small reverse leakage current.



In the photodiode fabrication process a thick intrinsic layer is inserted between the p-type and n-type layers. The middle layer may be either completely intrinsic, or very lightly doped to make it and n- layer. Light enters the device through a small window and is incident on the intrinsic material in which there are no carriers. The intrinsic material is made sufficiently thick so that the entire incident photons are absorbed by it. The electrons in the intrinsic material absorb most of the incident photons. The photons that are absorbed, add sufficient energy to generate carriers in the depletion region and thereby allow current to flow through the device.

Avalanche Photo Diode (APD):-

An avalanche photo diode (APD) is a PiPN device as shown in fig below.

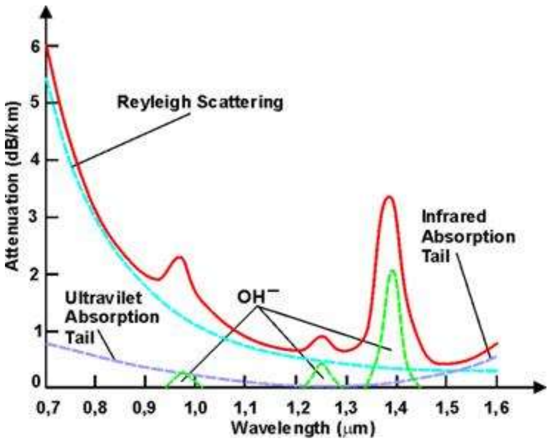


APD showing high electric field

APD is similar to PIN diode the exception is the addition of high intensity electric field region. In this region primary electron hole pairs are generated by the incident photons which are able to absorb enough kinetic energy from strong electric field to collide with the atoms present in this region, thus generating more electron hole pairs. The physical phenomenon behind the internal current gain is known as the impact ionization.

This impact ionization leads to avalanche breakdown in ordinary reverse bias. It requires very high reverse bias voltage in order that the new carriers created by impact ionization can themselves produce additional carriers by same mechanism. This process of generating more than one electron hole pair from incident photon through ionization process is referred to as the avalanche effect. Thus the avalanche multiplication results in amplification of photodiode current.

Losses in OFC:-



Light traveling in an optical fiber loses power over distance. The loss of power depends on the wavelength of the light and on the propagating material. The loss of power in light in an optical fiber is measured in decibels (dB). Fiber optic cable specifications express cable loss as attenuation per 1-km length as dB/km. This value is multiplied by the total length of the optical fiber in kilometers to determine the fiber's total loss in dB.

The different types of losses occurring in fiber optic cables are:

- *Rayleigh scattering losses*:- The glass in optical fibers is an amorphous (non-crystalline) solid which is formed by allowing the glass to cool from its molten state at high temperature until it freezes. While it is still plastic, the glass is drawn out under tension into its long fiber.
  During this forming process, sub microscopic variations in the density of the glass and in doping impurities are frozen into the glass behave as reflecting and refracting facets to scatter a small portion of the light passing through the glass. This results in the loss of light, and is called as *Rayleigh scattering losses*. It is found that these losses vary inversely with the fourth power of the wavelength.
- *Absorption losses*:- Ultraviolet absorption, infrared absorption and ion absorption contribute to absorption losses.
  1. ***Ultraviolet absorption:*** UV absorption takes place because of pure fused silica; valence electrons can be ionized into conduction electrons by light. This ionization amounts to a loss of energy in the light fields and contribute to transmission loss. The absorption does not only take place at a fixed wavelength, but occurs over a broadband which extends up into the visible portion, with decreased losses at higher wavelengths.
  2. **Infrared absorption:** IR absorption losses take place because photons of light energy are absorbed by the atoms within the glass molecules and converted to the random mechanical vibrations typical of heating. This results in the loss of light, and is called as infrared absorption losses
  3. **Ion resonance absorption:** A minute quality of water molecule, trapped in the glass contributes OH^- ions to the material, which exhibit absorption and is called ion resonance absorption. Absorption peaks occur at λ=0.5, 1.25, 1.39 μm within the visible spectrum.

- *Bending losses:-* there are two types of bending losses caused due to
  Micro bending
  Macro bending
  1. Micro bending is a microscopic bending of the core of the fiber that may result from different thermal contraction between core and cladding or because of kinking during handling. This micro bends act as scattering facets within the fiber and cause the energy loss inside the fiber.
  2. Macro bending is caused in the multi-fiber cables, where they are spiraled about a central cable core. These macro bends cause the energy loss inside the fiber.

DISTRIBUTION OF MARKS

2 MARK-2 QUESTION 4 MARKS
5 MARK-2 QUESTION 10 MARKS
TOTAL 14 MARKS

QUESTION BANK

1. Mention the conditions for total internal reflection.
2. Draw the different layers of Fiber Optic Cable.
3. Mention any two requirements of Light sources used in fiber optic communication.
4. Mention the advantages of optical Fiber communication system.
5. Discuss the relative advantages and disadvantages of optical fibers over metallic cables
6. Mention the conditions for light propagation in optical fibers
7. Draw the block diagram of FOC system.
8. Draw the block diagram of fiber optical communication system and explain the function of each block.
9. Mention the conditions for total internal reflection.
10. Explain the principle of light transmission in optical fibers
11. Draw the different layers of Fiber Optic Cable.
12. Explain the principle of light transmission in optical fibers
13. Explain step index profile and graded index profile in FOC.
14. Explain the working of LASER Diode
15. Explain step index profile and graded index profile in FOC.
16. Name the light sources used in optical fiber communication. What are the requirements of a good light source?
17. Mention two differences between LED and semiconductor LASER diode in fiber optic communications
18. What are the losses in optic fiber cables?
19. What are the losses present in optical fibers? Explain them.
20. Write a note on bending losses and absorption losses in optical fibers.
21. An optical fiber is made of glass core with refractive index 1.58 and clad with another glass of refractive index1.51. Launching takes place from air. Calculate
    i) Numerical aperture ii)Acceptance angel of the optical fiber
22. A glass clad fiber is made with a core glass of refractive index 1.55 and cladding is doped to give a fractional difference of 0.004. Find the refractive index of cladding, critical internal angle of reflection and numerical aperture.

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