MEERUT INSTITUTE OF ENGINEERING AND TECHNOLOGY, MEERUT

UNIT – V (B)

OPTICAL FIBER

Introduction:

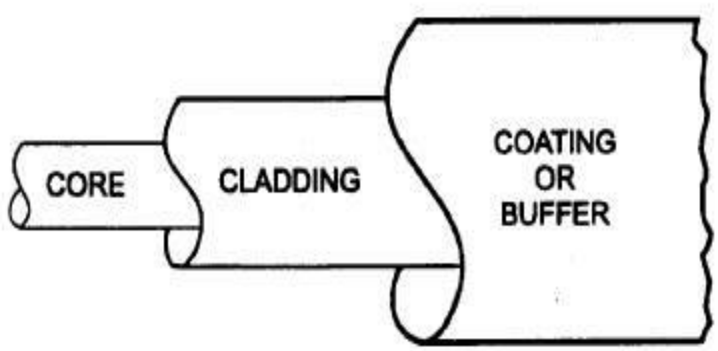
In case of electronic communication the information is normally carried out in the form of radio waves and microwaves through copper wire and coaxial cables. But they all have certain limitations. The use of light wave in place of radio waves and microwaves are more beneficial in comparison to the traditional communication techniques. This technology is known as Optical Fibre communication.
Optical fibres are made up of glass Or Plastic which is as thin as a human Hair. This works on the principle of “Total Internal Reflection”.

Q. Define Optical Fiber and describe construction of optical fiber.

Optical fiber is a hair like thin cylindrical structure. It works on the principle of Total Internal Reflection
It consists of three regions—

- **CORE**- It is the innermost cylinder with diameter 10-100 µm and refractive index n_1.Light beam is kept within the core using the phenomenon of Total Internal reflection.
- **CLADDING**-The core is surrounded by a glass or plastic material with refractive index n_2 .It provides some strength to core and keep light waves within the core. The difference between n_1 and n_2 is 10-3 µm.
- **SHEATH**-The core cladding system is enclosed in an outer jacket to protect it from abrasions, contaminations and moisture.

Many such fibers with individual jackets are grouped as cables that contain hundreds of fibers.



Q. Explain the different types of fibers on the basis of number of modes and refractive index.

<u>TYPES OF FIBER-</u>

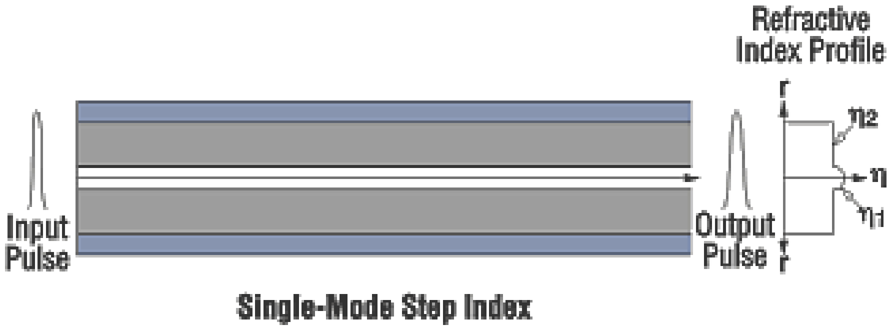
There are three types of optical fiber to meet different requirements-

(a) Step Index Single mode Fiber

(b) Step Index Multi mode Fiber

(c) Graded Index Multi mode Fiber

STEP INDEX SINGLE MODE FIBER-



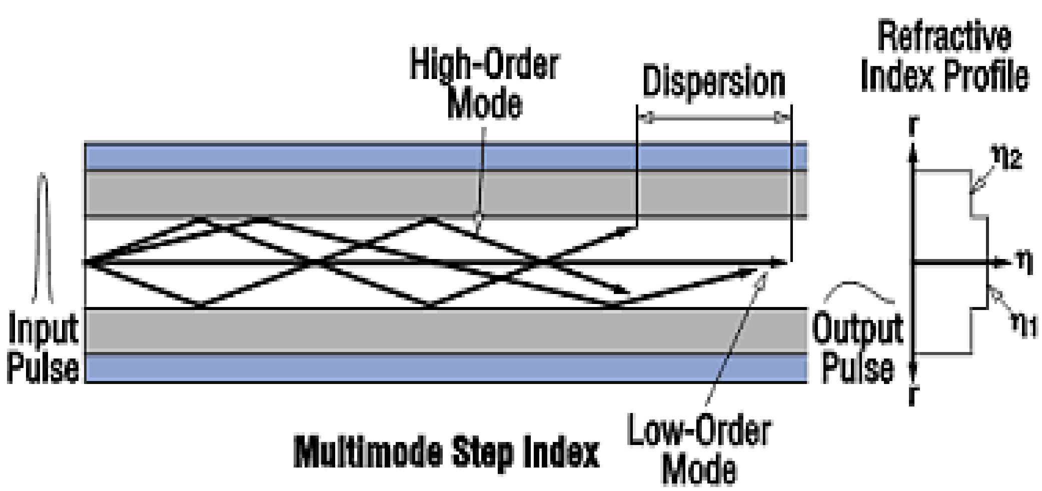
The single mode step index fiber has the distinct advantage of low dispersion, as only one mode is transmitted. It has high information carrying capacity.

Core diameter is less about 10µm thus only one mode can propagate through the fiber. It requires highly directional source such as LASER diode because of small core diameter, hence the cost is higher than multimode step index fiber. Single Mode Fibers are used for communication greater than 200m and frequently used under sea water.

For single mode optical fiber the diameter of the core must satisfy the relation,

$$d < \frac{0.766\lambda}{N.A} \quad \text{(Here, N.A. = Numerical Aperture)}$$

STEP INDEX MULTI MODE FIBER-



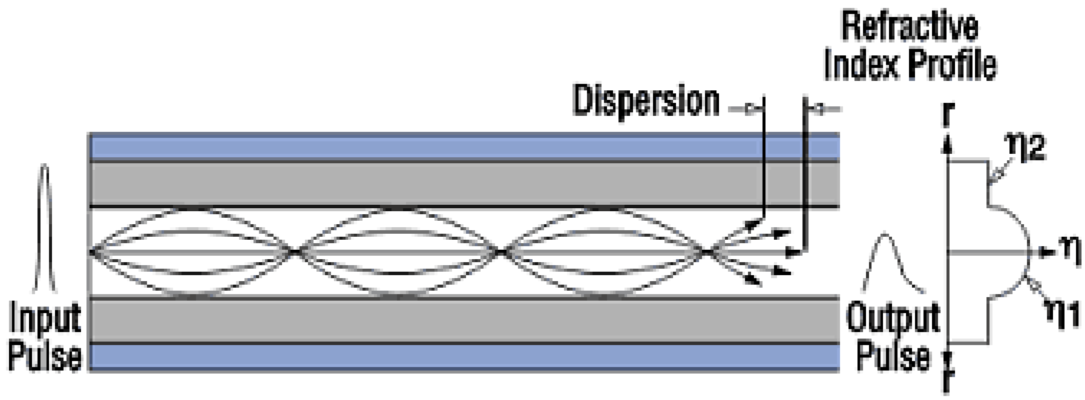
It has a core diameter of about 100µm large enough to propagate many signals of light. Different signals will travel at different distance, depending on their angle of TIR. so time taken is also different hence Rays that enter with a shallower angle travel by a more direct path, and arrive sooner than those enter at steeper angles (which reflect many more times off the core/cladding boundaries as they travel the length of the fiber). The arrival of different modes of the light at different times is called **Modal Dispersion**. A narrow pulse gets broadened when passes through multimode fiber so it reduces information carrying capacity. These fibers are used for short distances 200m range.

For multimode step index the diameter of the core must be,

$$d > \frac{0.766\lambda}{N.A}$$

In the case of multi-mode optical fibers, due to multiple signals through a core, it offers a "DISPERSION LOSS" while carrying information's.

GRADED INDEX MULTI MODE FIBER



Multimode Graded Index

It is less expensive and good to overcome with modal dispersion. In step index, core has a constant value but in graded index, refractive index of core has max value at axis and gradually decreases at core cladding boundary.

For graded index multi-mode optical fiber, the core must have the radius (r) as per the relation given below,

$$n(x) = n_1 \left[1 - 2\Delta \left(\frac{x}{r} \right)^P \right]^2$$

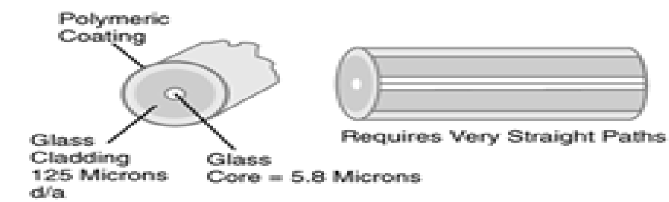
Where, n(x) = refractive index of the core at a distance x from the center of the core

n_1 = refractive index of center core

P = Index profile

And the number of mode is expressed as

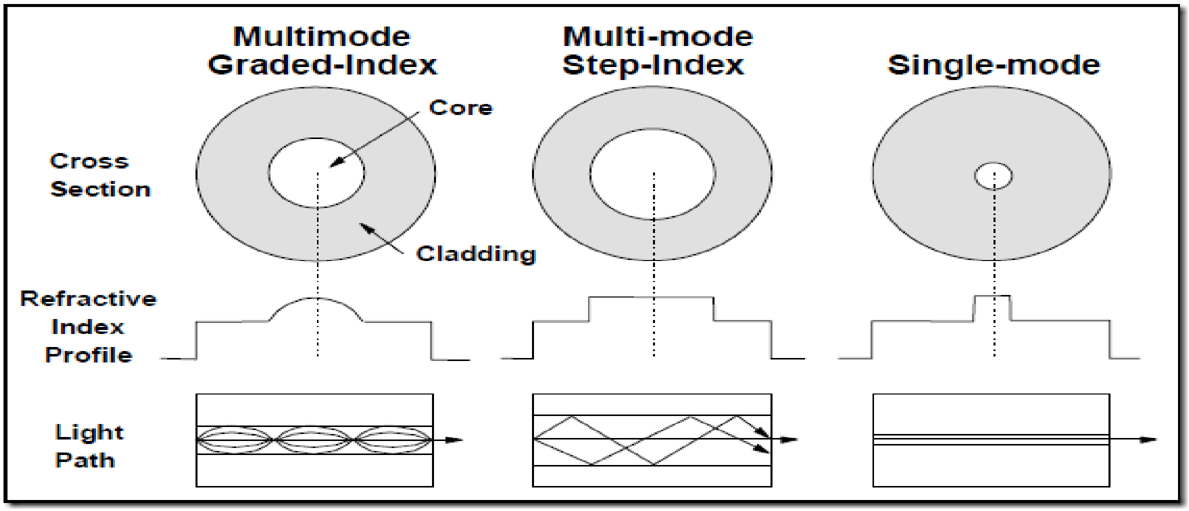
$$N = \left(\frac{P}{P+2} \right) \left[\frac{2\pi^2 r^2 (N.A.)^2}{\lambda^2} \right]$$

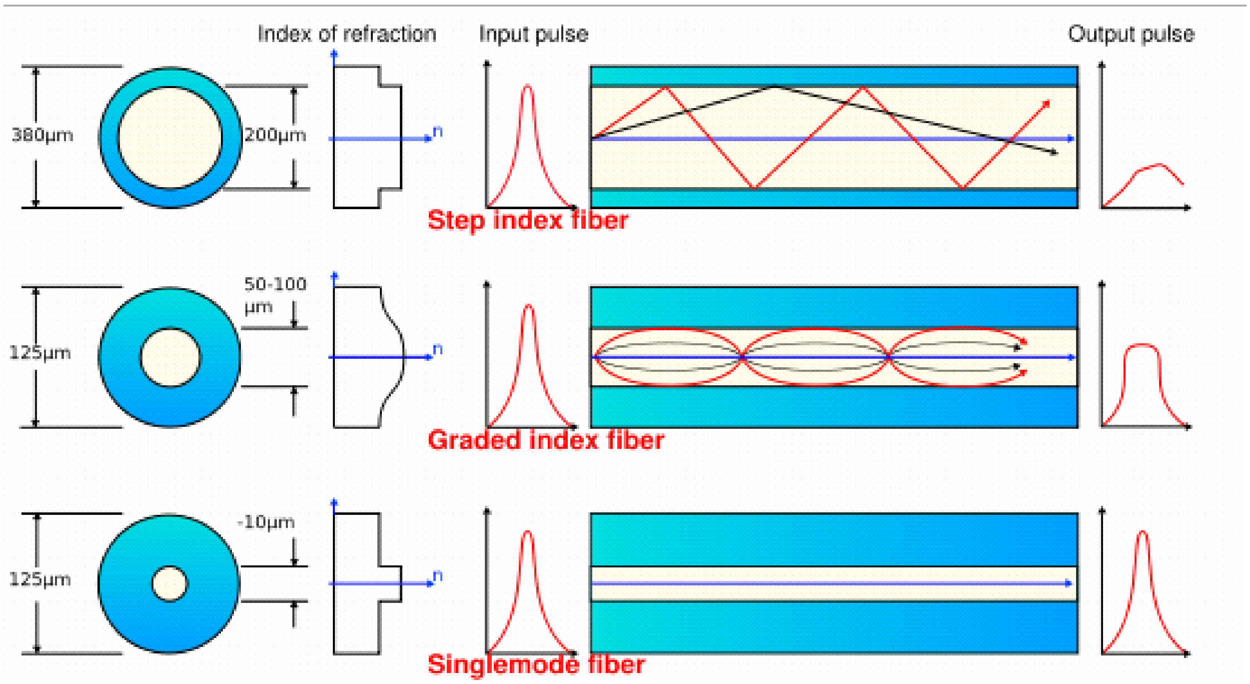


Single-Mode	Multimode
• Small Core • Less Dispersion • Suited for Long-Distance Applications (Up to ~ 3 km) • Uses Lasers as the Light Source Often Within Campus Backbones for Distances of Several Thousand Meters	• Larger Core Than Single-Mode Cable (50 Microns or Greater) • Allows Greater Dispersion and, Therefore, Loss of Signal • Used for Long-Distance Application, but Shorter Than Single-Mode (Up to ~ 2 km) • Uses LEDs as the Light Source Often Within LANs or Distances of a Couple Hundred Meters Within a Campus Network

Q. DIFFERENTIATE BETWEEN STEP INDEX AND GRADED INDEX FIBER

Step index	**Graded index**
1. Refractive index of core is constant.	1. Refractive index of core is max at core axis and min. at core-cladding boundary.
2. Light ray reflect abruptly at core cladding boundary	2. Light ray bend smoothly as reaches to cladding.
3. NA is large.	3. NA is small.
4. High attenuation.	4. Low attenuation.
5. pulse dispersion is large in multi mode fiber	5. pulse dispersion is small



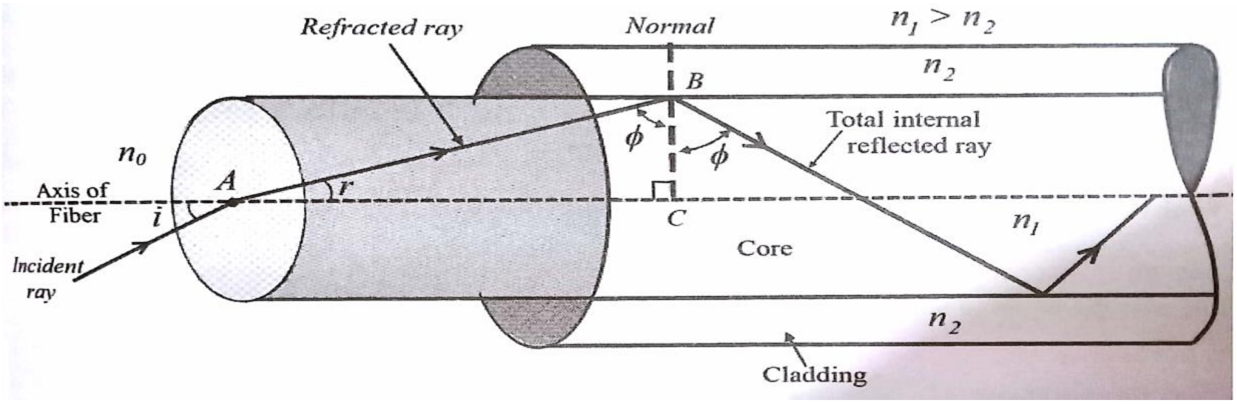


Q. Define acceptance angle. Find the expression for acceptance angle and numerical aperture and V number

<u>ACCEPTANCE ANGLE AND ACCEPTANCE CONE</u>

As the ray makes angle greater than critical angle, the light rays undergo TIR and those which are less than Critical angle, are either absorbed or scattered. The half-angle of the cone within which incident light is totally internally reflected is defined as Acceptance angle of the cone. It is equal to sin-1(NA). This angle is different for different fibers and depends on ref. index and diameter of core..

Let the light beam enters at an angle (i) to the axis of optical fiber. The ray gets refracted at an angle (r) and strikes the core cladding interface at an angle (Φ). For an angle (Φ), more than the critical angle, the light undergo the “Total Internal Reflection” and light will stay within optical fiber and propagate.



$$\text{According to Snell's Law} \quad \frac{\sin i}{\sin r} = \frac{n_1}{n_0} \text{-------------}(1)$$

from ΔABC;

$$\sin r = \sin(90 - \phi)$$

$$\sin r = \cos\phi$$

so the equation-1 will be

$$\frac{\sin i}{\cos\phi} = \frac{n_1}{n_0}$$

$$\sin i = \frac{n_1}{n_0}\cos\phi \text{-------------}(2)$$

since $\sin\phi = \frac{n_2}{n_1}$, so this will give

$$\cos\phi = \sqrt{1 - \sin^2}$$

$$\cos\phi = \sqrt{1 - \frac{{n_2}^2}{{n_1}^2}} \text{----------------}(3)$$

Now substitute the value of equation-3 in equation-2; we get

$$\sin i = \frac{n_1}{n_0}\sqrt{1 - \frac{{n_2}^2}{{n_1}^2}}$$

$$\sin i = \frac{n_1}{n_0}\sqrt{\frac{{n_1}^2 - {n_2}^2}{{n_1}^2}}$$

$$\sin i = \frac{\sqrt{{n_1}^2 - {n_2}^2}}{n_0} \text{----------------}(4)$$

According to figure the light is launched from air i.e. n_0=1;

$$\mathrm{Sin}\, i = \sqrt{n_1^{\,2} - n_2^{\,2}}$$

$$\mathrm{i} = \mathrm{Sin}^{-1}\left(\sqrt{n_1^{\,2} - n_2^{\,2}}\right) ----------------- (5)$$

OR $$\mathrm{i}_{\max} = \mathrm{Sin}^{-1}(N.A.);$$

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

So, Equation-5 gives the acceptance angle for the optical fibers.

Acceptance Cone:

Here acceptance cone of the fiber is the maximum incidence angle at which light can follow Total Internal Reflection (TIR) for propagation.

$$\text{Acceptance Cone;} \qquad 2\mathrm{i}_{\max} = 2\mathrm{Sin}^{-1}\left(\sqrt{n_1^{\,2} - n_2^{\,2}}\right)$$

Relation between N.A. and Fractional refractive index change (Δ):

Fractional change in refractive index will be given as:

$$\Delta = \frac{\mathrm{n}_1 - n_2}{n_1}$$

$$\mathrm{N.A.} = \left(\sqrt{n_1^{\,2} - n_2^{\,2}}\right)$$

$$where, \quad \mathrm{N.A.} = \sqrt{(n_1 - n_2)(n_1 + n_2)}$$

$$\mathrm{N.A.} = \sqrt{\left(\frac{n_1 - n_2}{n_1}\right).\left(\frac{n_1 + n_2}{2}\right).(2n_1)}$$

$$\mathrm{N.A.} = \sqrt{\Delta . n_1 .(2n_1)} \qquad \left[\text{here, } \Delta = \frac{n_1 - n_2}{n_1} \quad and \;\; n_1 = \frac{n_1 + n_2}{2}\right]$$

$$\mathrm{N.A.} = n_1\sqrt{2\Delta}$$

<u>V-NUMBER-</u> The no. of modes supported by an optical fibers obtained by an important parameter called normalized frequency or cut-off parameter or V-parameter or V-number of fiber.

$$V = \frac{2\pi a}{\lambda}\sqrt{\left(n_1^{\,2} - n_2^{\,2}\right)} = \frac{2\pi a}{\lambda} N.A. = \frac{2\pi a}{\lambda} n_1\sqrt{2\Delta}$$

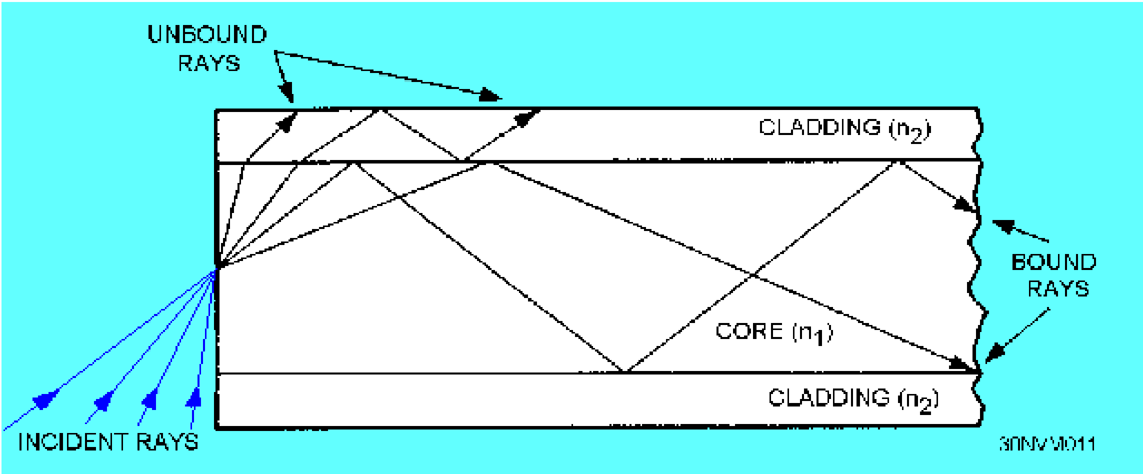
So no. of modes supported by step index fiber is $N_{\max} = \frac{V^2}{2}$

For single mode fiber V < 2.405, For multi-mode fiber V > 2.405. Wavelength corresponding to V = 2.405 is called cut-off wavelength of fiber.

$$\lambda_c = \frac{\lambda V}{2.405}$$

And no. of modes for graded index fiber $N_{\max} = \frac{V^2}{4}$

Q. Discuss the different type of losses in optical fibre. OR discuss attenuation and signal losses in optical fiber.



When signals guided through an optical fiber, the reduction in amplitude or intensity of light signal is called attenuation. Lower is its value, greater be the intensity of signal at receiving end. Attenuation in an optical fiber is caused by absorption, scattering, and bending losses. **Attenuation** is the loss of optical power as light travels along the fiber. Signal attenuation is defined as the ratio of optical 0utput power (P_i) to the optical input power (P_o). Optical input power is the power of signals which given to fiber from an optical source. Optical output power is the signal power received at the fiber end or optical detector. The following equation defines signal attenuation as a unit of length:

Attenuation loss α is measured in decibels i.e. in dB/Km.

$$\alpha = \frac{10}{L}\log\left(\frac{P_{out}}{P_{in}}\right)$$

Here length (L) is expressed in kilometers. Therefore, the unit of attenuation is decibels/kilometer (dB/km).

Attenuation is caused by absorption, scattering, and bending losses. Each mechanism of loss is influenced by fiber-material properties and fiber structure.

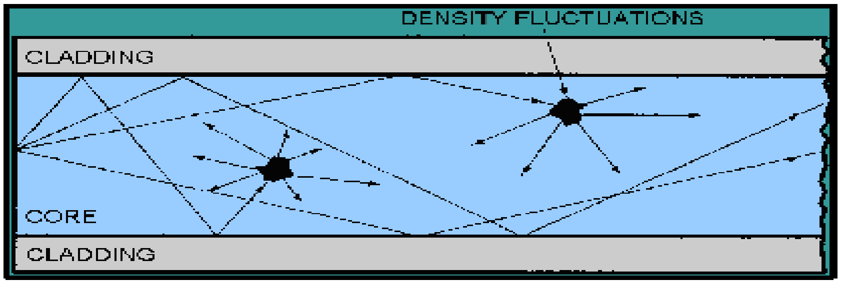
1. **ABSORPTION LOSS-** Absorption is a major cause of signal loss in an optical fiber during the propagation of signals. Broadly the absorption in optical fiber is due to following resaons.
    a) Imperfections in the atomic structure of the fiber material
    b) The intrinsic or basic fiber-material properties
    c) The extrinsic (presence of impurities) fiber-material properties

(a) Imperfections in the atomic structure- Imperfections in the atomic structure induce absorption by the presence of missing molecules or oxygen defects. Absorption is also induced by the diffusion of hydrogen molecules into the glass fiber. Since intrinsic and extrinsic material properties are the main cause of absorption, they are discussed below.

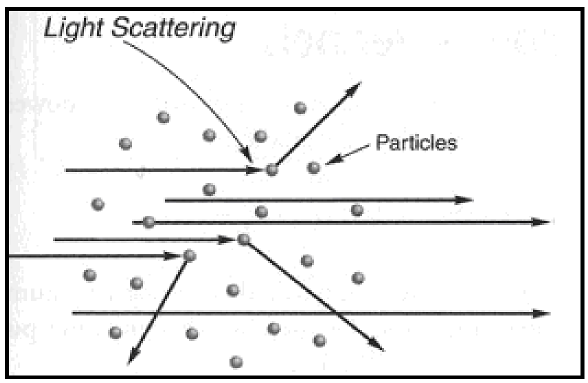
(b) INTRINSIC ABSORPTION-Intrinsic absorption is caused by basic fiber-material properties. If an optical fiber were absolutely pure, with no imperfections or impurities, then all absorption would be intrinsic. Intrinsic absorption sets the minimal level of absorption.

(c) EXTRINSIC ABSORPTION - Extrinsic absorption is caused by impurities introduced into the fiber material. Trace metal impurities, such as iron, nickel, and chromium, are introduced into the fiber during fabrication. Extrinsic absorption is caused by the electronic transition of these metal ions from one energy level to another.

2. SCATTERING - Basically, scattering losses are caused by the interaction of light with density fluctuations within a fiber. Density changes are produced when optical fibers are manufactured. During manufacturing, regions of higher and lower molecular density areas, relative to the average density of the fiber, are created.



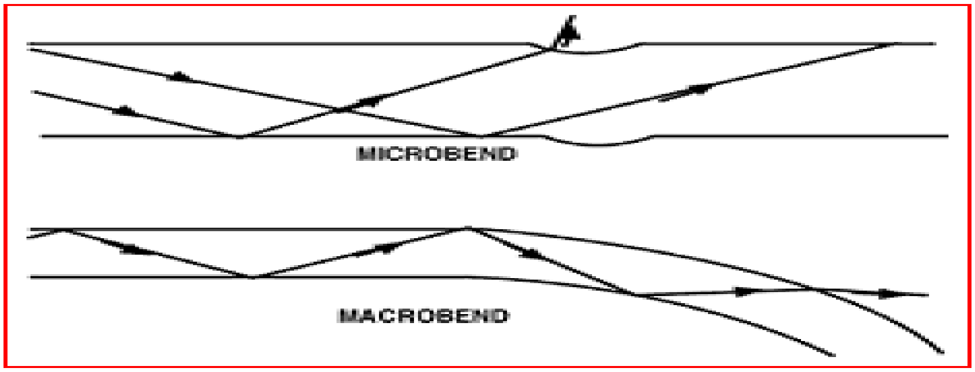
(a) <u>RAYLEIGH SCATTERING LOSS</u>- Rayleigh scattering is a loss mechanism arising from local microscopic fluctuation in density. Silica molecules move randomly in a molten state and freezes during fiber fabrication. Density fluctuation leads to random fluctuations of the refractive index on a scale smaller than the optical wavelength. Light scattering in such a medium is known as Rayleigh scattering. Scattering depends not on the specific type of material but on the size of the particles relative to the wavelength of light. The amount of scattering increases rapidly as the wavelength decreases.



(b) <u>WAVEGUIDE SCATTERING LOSS-</u> An ideal single mode fiber with a perfect cylindrical geometry guides the optical mode without energy leakage into the cladding layer. But in reality, imperfections at the core-cladding interface, such as random core-radius variations, can lead to additional losses which contribute to the total fiber loss. The physical process behind such losses is *Mie scattering*, occurring because of index inhomogeneities on a scale longer than the optical wavelength.

3. <u>BENDING LOSS</u> - Bending the fiber also causes attenuation. Bending loss is classified according to the bend radius of curvature: micro-bend loss or macro-bend loss.

(a) Macro-bends are small microscopic bends of the fiber axis that occur mainly when a fiber is cabled. **Macrobends** are bends having a large radius of curvature relative to the fiber diameter. Macrobend and Macrobend losses are very important loss mechanisms. Fiber loss caused by microbending can still occur even if the fiber is cabled correctly. During installation, if fibers are bent too sharply, Macrobend losses will occur.



(b) Micro-bend losses are caused by small discontinuities or imperfections in the fiber. Uneven coating applications and improper cabling procedures increase microbend loss. External forces are also a source of microbends. An external force deforms the cabled jacket surrounding the fiber but causes only a small bend in the fiber. Microbends change the path that propagating modes take, as shown in figure. **Microbend loss** increases attenuation.

SIGNAL DISPERSION

Dispersion is the phenomenon in which phase velocity of wave depends on its frequency.

While propagating through the fiber the phenomenon of spreading or broadening of pulses is pulse dispersion.

1. INTERMODAL OR MODAL DISPERSION-It is dominant source of dispersion in MMF and does not exist in SMF. Due to different wavelength each ray takes different time so adjacent pulses overlap at output. Pulse spreading determines min. separation between adjacent pulses hence determine max. Information carrying capacity of fiber. It also depends upon fiber distance and increases with increasing distance. Thus amplitude decreases and due to overlapping pulses become indistinguishable.

2. INTRAMODAL OR CHROMATIC DISPERSION-

It occurs in all types of fibers. Optical signal emits a band of frequency so due to propagation delay each transmitted wave gets broadened. This is called intramodal dispersion.

(a) Material Dispersion- Material dispersion occurs because the spreading of a light pulse is dependent on the wavelengths' interaction with the refractive index of the fiber core. Different wavelengths travel at different speeds in the fiber material. Different wavelengths of a light pulse that enter a fiber at one time exit the fiber at different times. Material dispersion is a function of the source spectral width. The spectral width specifies the range of wavelengths that can propagate in the fiber. Material dispersion is less at longer wavelengths.

(b) <u>Waveguide dispersion-</u> Waveguide dispersion occurs because the mode propagation constant is a function of the size of the fiber's core relative to the wavelength of operation. Waveguide dispersion also occurs because light propagates differently in the core than in the cladding.

<u>Q. WRITE APPLICATION OF OPTICAL FIBER-</u>

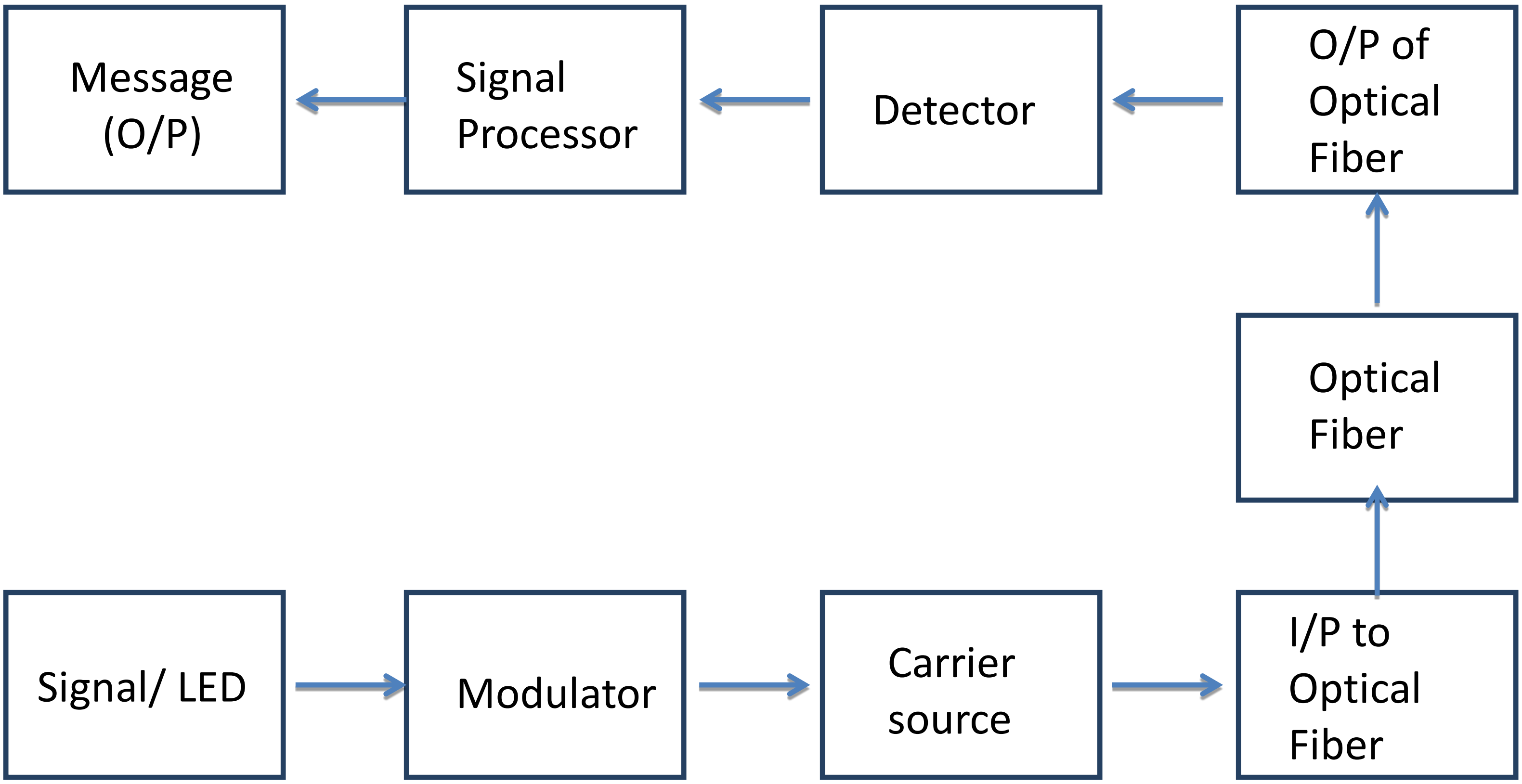
1. These are used in broadcast T.V. and cable T.V.
2. Used for transmission of digital data generated by computer .In military it is used for secret communication, command and control link on ships and aircrafts.
3. In building so, optical fibers are used for to route sunlight from roof to other parts of buildings.
4. Are used to form sensors to measure physical and chemical parameters.
5. Optical fiber can couple two circuits without any electric link.
6. Used to provide signal amplification and carry light to display units.

<u>Q. GIVE ADVANTAGE OF OPTICAL FIBER OVER COAXIAL CABLE (OR COPPER WIRE)</u>

1. Optical frequency range is very high i.e. light has a very high information carrying capacity hundreds times greater than that of copper wire.
2. Optical fibers are more economical in long run.
3. Optical fibers can accommodate much higher band width.
4. Optical fibers are light in weight so they are easier to transport and handle and no connection is required to connect transmitter and receiver.
5. Optical fibers can withstand environmental hazards better and have a long life.
6. Silica which is principle material for optical fiber is easily available, and much cheaper in cost as compare to copper wire.
7. Dielectric nature of optical fiber is an important advantageous feature. This provides optical immunity to electromagnetic interference.

Q. Optical Fiber Communication Block diagram:

1. As we know that the optical fiber works on Total International Reflection (TIR) across the core-cladding interface. So whenever the incidence angle of input signal is greater than the critical angle, the input signals start propagating through the core of optical cable.
2. So because of this property, optical fibers can be used for communication system. It has many advantages over the traditional communication system of copper wires.



1. **Signal/ LED**: It will convert the non-electrical message to electrical or optical signals
2. **Modulator**: It will increases the energy of the signals
3. **Carrier Source**: It will create a signal on which the information can be modulated
4. **Channel Couples (I/P)**: It will make incident of the signal to the optical fiber
5. **Optical Fiber**: It will carry a signal by Total Internal Reflection
6. **Detector**: The function of this point is to separate the information from a carrier waves.
7. **Signal Processor**: It will Include the amplification and filtering process of the signals/ messages
8. **Message (O/P)**: This will be the final output of the message/ signals at the other end of the communication.

END of UNIT