1.5 ABSORPTION LOSSES

Absorption in optical fibers is explained by three factors: Imperfections in the atomic structure of the fiber material.

- The intrinsic or basic fiber-material properties.
- The extrinsic (presence of impurities) fiber-material properties
- 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.

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

Extrinsic Absorption.- Extrinsic absorption is caused by impurities introduced into the fiber material. Trace metal impurities, such as iron, nickel, and chromium, OH ions 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

Scattering losses

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. Light traveling through the fiber interacts with the density areas as shown in Light is then partially scattered in all direction.

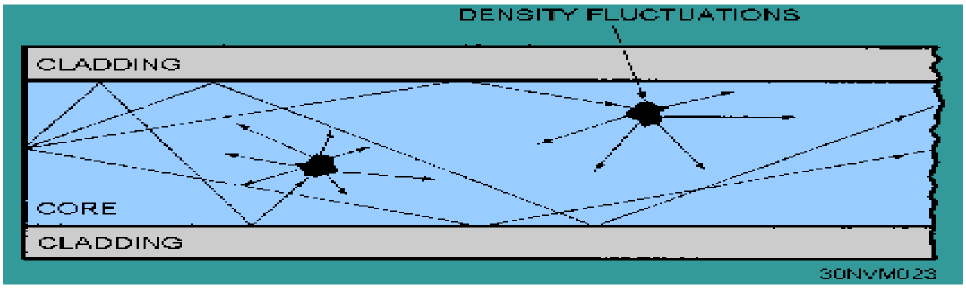

Figure 1.5.1 Scattering process

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 73]

In commercial fibers operating between 700-nm and 1600-nm wavelength, the main source of loss is called Rayleigh scattering. As the wavelength increases, the loss caused by Rayleigh scattering decreases. If the size of the defect is greater than one-tenth of the wavelength of light, the scattering mechanism is called Mie scattering.

Linear scattering losses

1. Rayleigh scattering

It occurs because the molecules of silicon dioxide have some freedom when adjacent to one another. Thus, setup at irregular positions and distances with respect to one another when the glass is rapidly cooled during the final stage of the fabrication process. Those structural variations are seen by light as variations in the refractive index, thus causing the light to reflect – that is, to scatter – in different directions

- **Rayleigh scattering** is a scattering of light by particles much smaller than the wavelength of the light, which may be individual atoms or molecules.
- Rayleigh scattering is a process in which light is scattered by a small spherical volume of variant refractive index, such as a particle, bubble, droplet, or even a density fluctuation.

As light travels in the core, it interacts with the silica molecules in the core. Rayleigh scattering is the result of these elastic collisions between the light wave and the silica molecules in the fiber. Rayleigh scattering accounts for about 96 percent of attenuation in optical fiber

Causes of Rayleigh Scattering:

It results from non-ideal physical properties of the manufactured fiber. It results from inhomogeneities in the core and cladding.

Because of these inhomogeneities problems occur like –

a) Fluctuation in refractive index

b) density and compositional variations.

•

Minimizing of Rayleigh Scattering:

Rayleigh scattering is caused due to compositional variations which can be reduced by improved fabrication.

Equation of Rayleigh Scattering:

Light scattering can be divided into three domains based on a dimensionless size parameter, α which is defined as

$$\mathbf{A} = \pi D_p / \lambda$$

where πD_p is the circumference(The boundary line of a circle) of a particle and λ is the wavelength of incident radiation. Based on the value of α, these domains are:

$\alpha \ll 1$: Rayleigh scattering (small particle compared to wavelength of light) $\alpha \approx 1$: Mie scattering (particle about the same size as wavelength of light)

Mie scattering

Non perfect cylindrical structure of the fiber and imperfections like irregularities in the core-cladding interface, diameter fluctuations, strains and bubbles may create linear scattering which is termed as Mie scattering

Mie scattering is a scattering of light by particles approximately equal to the wavelength of the light, which may be individual atoms or molecules.

Causes of Mie Scattering:

- Occurred due to inhomogeneities in the composition of silica. (i.e. inhomogeneities in the density of SiO_2)
- Irregularities in the core-cladding interface, Difference in core cladding refractive index, Diameter fluctuations
- Due to presence of strains and bubbles.

The scattering caused by such in homogeneities is mainly in the forward direction depending upon the fiber material, design and manufacture.

Minimizing of Mie scattering

Mie scattering is mainly caused by in homogeneities which can be minimized by

- Removing imperfection due to glass manufacturing process
- Carefully controlled extrusion(To push or thrust out) and coating of the fiber Both

Mie and Rayleigh scattering are considered elastic scattering (elastic scattering is also called Linear scattering) processes, in which the energy (and thus wavelength and frequency) of the light is not substantially changed.

Nonlinear scattering losses

Specially at high optical power levels scattering causes disproportionate attenuation, due to non linear behavior. Because of this non linear scattering the optical power from one mode is transferred in either the forward or backward direction to the same, or other modes, at different frequencies. The two dominant types of non linear scattering are :

a) Stimulated Brillouin Scattering and

b) Stimulated Raman Scattering.

a) Stimulated Brillouin Scattering:

This is defined as the modulation of light through thermal molecular vibration within the fiber. The scattered light contains upper and lower side bands along with incident light frequency. An incident photon produces a scattered photon as well as a photon of acoustic frequency. The frequency shift is maximum in the backward direction and it is reduced to zero in the forward direction. The threshold optical power for Brillion scattering is proportional to $d^2\lambda^2\alpha_B$

b) Stimulated Raman Scattering:

Here, the scattered light consists of a scattered photon and a high frequency optical photon. Further, this occurs both in the forward and backward direction in the optical fiber. The threshold optical power for Raman scattering is about three orders of magnitude higher than the Brillouin threshold for the given fiber, The threshold optical power for Raman scattering is proportional to $d^2\lambda^2\alpha_R$

1.7 SPLICERS

For longer distance communication, we have to connect one fiber with other fiber and mean while the losses must be minimized. The process of connecting the two fibers for permanent requirement is called Splicing. Depend upon requirement splicing is classified into two type. They are,

1. Splices – For permanent connections.
2. Connectors – For temporary connections.

Types of splicing

There are two types of splices. They are (i). Mechanical splices (ii). Fusion splices.

Mechanical splices

a. Elastomeric splice

It is made by an elastomer material. It consists of a hole, so that we have to insert the two fibers from two ends for rigid hold. The elastomer is covered by a glass sleeve with ends in such a way that it aligns the fibers into the elastomeric splice. The gel has the same refractive index is used as an adhesive. Thus the fibers are connected.

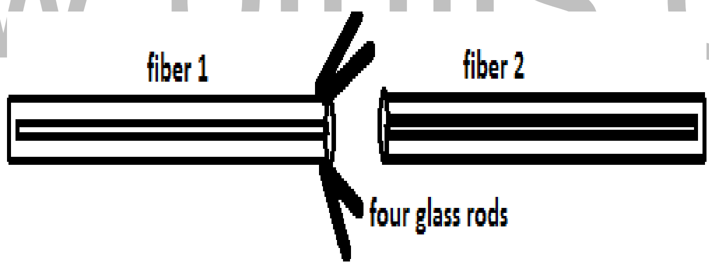

Figure 1.7.1 Elastometric Splice

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 131]

b. Four Rod Splices:

The four glass rods are attached with one end of the fiber to hold another fiber firmly. Initially the rods curve slightly outward, so that the fiber can be easily inserted into it. By a suitable mechanical pressure the rods are made to be tightly clamping the two fibers. Here also gel is used for adhesion.

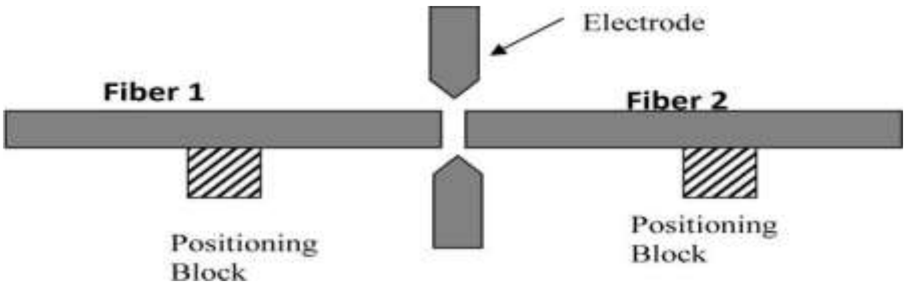

Figure 1.7.2 Four Rod Splice

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 132]

c. **Fusion Splices:** Here two ends of the fiber is fused together with the help of a special equipment, using a high voltage electric arc. Hence, these splices are called fusion splices. Here the losses are minimized due to self-alignment system.

Connectors and fiber termination

(i) Butt-joint connectors

It is made up of a special type of material called ferrule, composing of metal/glass/plastic materials. The fiber is send into the drilled hole of the ferrules and is aligned properly with the help of the alignment sleeve. The distance between the fibers is minimized by adjusting the alignment sleeve and the guide ring, and is used to match the ends of the fibers. Once the matching was done, the light from one fiber can be easily coupled to the other fiber with minimum losses.

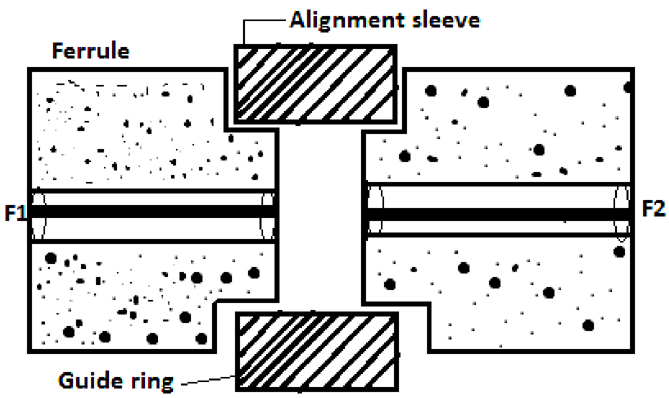

Figure 1.7.3 Butt Joint Connector

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 133]

(ii) Expanded beam connectors:

It consists of a collimating lens at the end of transmitting fiber and focusing lens at entrance of the receiving fiber. Light coming out from the transmitting fiber is made to fall over the collimating lens. The collimating lens makes the beam parallel and is focused into the focusing lens. After passing through the focusing lens, the light is coupled into the receiving fiber without any loss. Thus the loss is minimized.

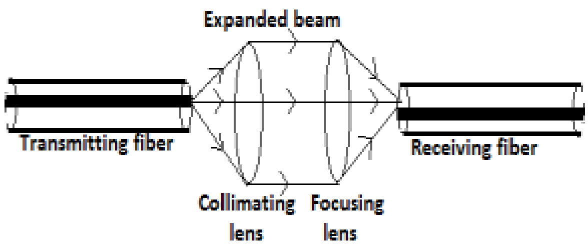

Figure 1.7.4 Expanded beam Connector

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 135]

1.1 CONSTRUCTION OF OPTICAL FIBER CABLE

An optical fiber is a glass or plastic fiber that carries light along its length. Fiber optics is the overlap of applied science and engineering concerned with the design and application of optical fibers. Optical fibers are widely used in fiber optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) because light has high frequency than any other form of radio signal than other forms of communications. Light is kept in the core of the optical fiber by total internal reflection. This causes the fiber to act as a waveguide. Fibers are used instead of metal wires because signals travel along them with less loss, and they are also immune to electromagnetic interference, which is caused by thunderstorm. Fibers are also used for illumination and are wrapped in bundles so they can be used to carry images, thus allowing viewing in tight spaces. Specially designed fibers are used for a variety of other applications, including sensors and fiber lasers.

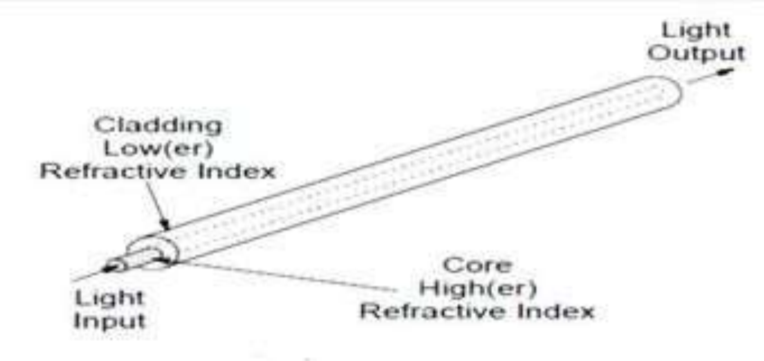

Figure 1.1.1 Construction of Fibre

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 12]

An optical fiber is a very thin strand of silica glass in geometry quite like a human hair. In reality it is a very narrow, very long glass cylinder with special characteristics. When light enters one end of the fiber it travels until it leaves the fiber at the other end. An optical fiber consists of two parts: the core and the cladding. The core is a narrow cylindrical strand of glass and the cladding is a tubular jacket surrounding it. The core has a (slightly) higher refractive index than the cladding. Light travelling along the core is confined by the mirror to stay within it even when the fiber bends around a corner.

A fiber optic cable has an additional coating around the cladding called the jacket. The jacket usually consists of one or more layers of polymer. Its role is to protect the core and cladding from shocks that might affect their optical or physical properties. It acts as a shock 14 absorber. The jacket also provides protection from abrasions, solvents and other contaminants. The jacket does not have any optical properties that might affect the propagation of light within the fiber optic cable.

Guiding mechanism in optical fiber

Light ray is injected into the fiber optic cable on the right. If the light ray is injected and strikes the core-to-cladding interface at an angle greater than an entity called the critical angle then it is reflected back into the core. Since the angle of incidence is always equal to the angle of reflection the reflected light will again be reflected. The light ray will then continue this bouncing path down the length of the fiber optic cable. If the light ray strikes the core-to-cladding interface at an angle less than the critical angle then it passes into the cladding where it is attenuated very rapidly with propagation distance. Light can be guided down the fiber optic cable if it enters at less than the critical angle.

This angle is fixed by the indices of refraction of the core and cladding and is given by the formula

The critical angle is measured from the cylindrical axis of the core. By way of example, if n1

= 1.446 and n2 = 1.430 then a quick computation will show that the critical angle is 8.53 degrees, a fairly small angle.

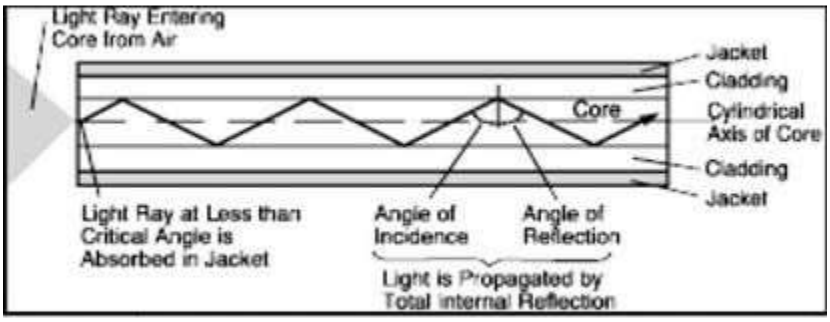

Figure 1.1.2 Mechanism of Light Wave guide Fibre

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 13]

Of course, it be noted that a light ray enters the core from the air outside, to the left of Figure. The refractive index of the air must be taken into account in order to assure that a light ray in the core will be at an angle less than the critical angle. This can be done fairly simply.

Suppose a light ray enters the core from the air at an angle less than an entity called the external acceptance angle It will be guided down the core.

Basic component of optical fiber communication

1 Transmitters - Fiber optic transmitters are devices that include an LED or laser source, and signal conditioning electronics, to inject a signal into fiber. The modulated light may be turned on or off, or may be linearly varied in intensity between two predetermined levels.

2 Fiber – It is the medium to guide the light from the transmitter to receiver.

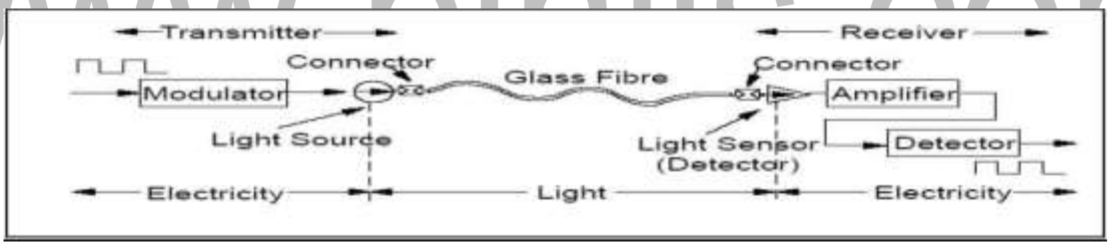

Figure 1.1.3 The basic components of an optical fiber communication

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 14]

3 Receivers – Fiber optic receivers are instruments that convert light into electrical signals. They contain a photodiode semiconductor, signal conditioning circuitry, and an amplifier at the receiver end.

1.3 DIFFERENT TYPES OF FIBERS AND THEIR PROPERTIES

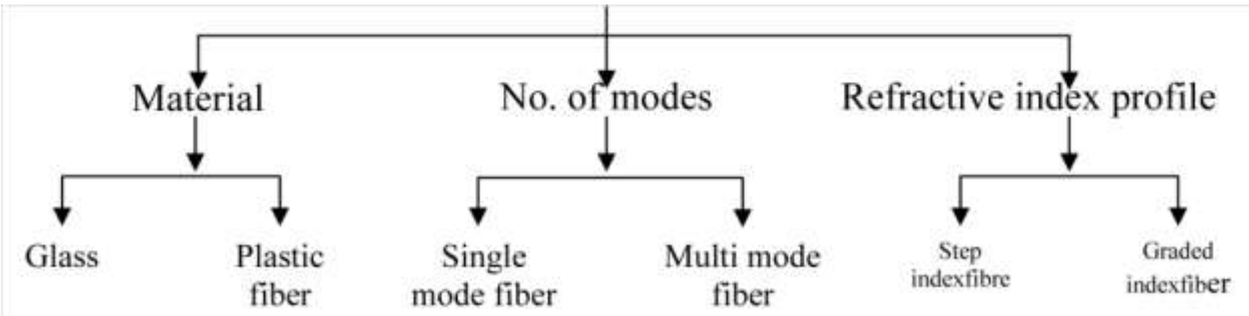

Figure 1.3.1 Different Types of Fibre

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 31]

Glass And Plastic Fibers

Based on materials in which the fibers are made it is classified into two types as follows:

Glass fibers

If the fibers are made up of mixture of metal oxides and silica glasses are called glass fibers. Examples:-

- Core: SiO_2;cladding: P_2O_3– SiO_2
- Core: GeO_2– SiO_2;cladding: SiO_2

Plastic fibers

If the fibers are made up plastics which can be handled without any care due to its toughness and durability it is called plastic fiber.

Examples:-

The plastic fibers are made by any one of the following combinations of core and cladding.

- Core:Polymethylmethacrylate; cladding: co-polymer
- Core: Polystyrene; cladding: Methyl methacrylate

Single and multimode fibers

Mode is described by the nature of propagation of electromagnetic waves in a wave guide. Based on the modes of propagation the fibers are classified into two types viz.

(i) Single mode fibers

(ii) Multi mode fibers

(i) Single mode fibers

1. It has very small core diameter so that it can allow only one mode of propagation and hence called single mode fibers.
2. The cladding diameter must be very large compared to the core diameter.
3. Thus in the case of a single mode fiber, the optical loss is very much reduced.

Structure

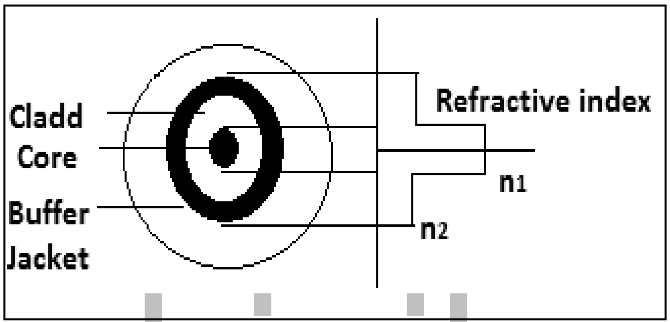

Figure 1.3.2 Structure of Single Mode Fibre

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 34]

Core diameter: 5 – 10 μm

Cladding diameter : Around 125 μm Protective layer: 250 to 1000 μm

Numerical aperture: 0.08 to 0.10 Band width: More than 50 MHz km

(ii) Multi-mode fibers:

1. Here the optical dispersion may occur.
2. They are made by multi-component glass materials.
3. The core diameter is larger than the diameter of the single mode fibers, so that it can allow many modes to propagate through it and hence called as multimode fibers.

Structure:

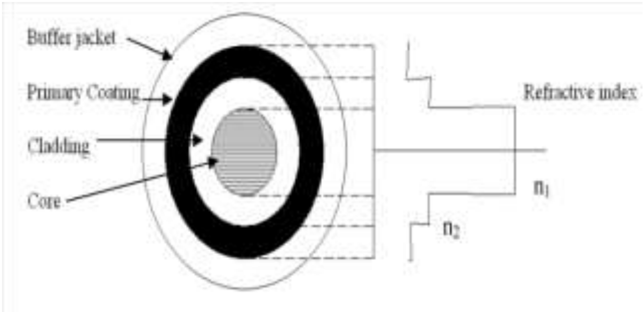

Figure 1.3.3 Structure of Multi Mode Fibre

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 35]

Core diameter:50 – 350 μm Cladding diameter: 125 – 500 μm

Protective layer: 250 to 1100 μm

Numerical aperture: 0.12 to 0.5 Band width:Less than 50 MHz km

Step index and graded index fibers:-

Based on the variation in the refractive index of the core and the cladding, the fibers are classified into two types, viz.

(i) Step index fiber (ii) Graded index fiber

STEP INDEX FIBER

Here the refractive indices of air, cladding and core vary step by step and hence it is called as step index fiber.Thereare two types of step index fibers. They are,

1. Step index single mode fiber –there is dispersion will occur.
2. Step index multi modefiber -- there is intermodal dispersion will occur.

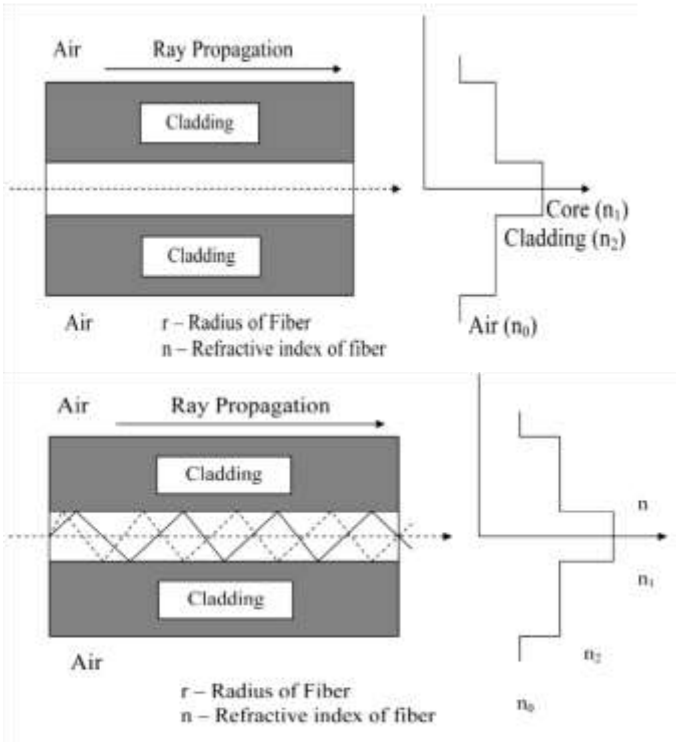

Figure 1.3.4 Structure of Step Index Fibre

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 37]

Graded Index Fiber

Here the refractive index of the core varies radically from the axis of the fiber. The refractive index of the core is large along the fiber axis and it's gradually decreases thus it is called as graded index fiber.

Here the refractive index becomes small at the core – cladding interface. In general the graded index fibers will be of multimode system. The multimode graded index fiber has very less intermodal dispersion compared to multimode step index fiber.

1.6 DISPERSION

Dispersion occurs when a pulse of light is spread out during transmission on the fiber. A short pulse becomes longer and ultimately joins with the pulse behind, making recovery of a reliable bit stream impossible. (In most communications systems bits of information are sent as pulses of light. 1 = light, 0 = dark. But even in analogue transmission systems where information is sent as a continuous series of changes in the signal, dispersion causes distortion.)

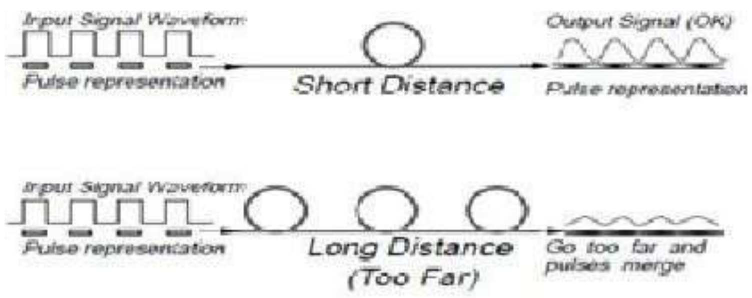

Figure 1.6.1 Effect of Dispersion

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 94]

Types of dispersion

There are many kinds of dispersion, each of which works in a different way, but the most important three are discussed below:

Material dispersion (chromatic dispersion):-

Both lasers and LEDs produce a range of optical wavelengths (a band Of light) rather than a single narrow wavelength. The fiber has different refractive index characteristics at different wavelengths and therefore each wavelength will travel at a different speed in the fiber. Thus, some wavelengths arrive before others and a signal pulse disperses (or smears out).

Intermodal dispersion (Mode Dispersion):-

When using multimode fiber, the light is able to take many different paths or "modes" as it travels within the fiber. The distance traveled by light in each mode is different from the distance travelled in other modes. When a pulse is sent, parts of that pulse (rays or quanta) take many different modes (usually all available modes). Therefore, some components of the pulse will arrive before others. The difference between the arrival times of light taking the fastest mode versus the slowest obviously gets greater as the distance gets greater.

Waveguide dispersion:-

Waveguide dispersion is a very complex effect and is caused by the shape and index profile of the fiber core. However, this can be controlled by careful design and, in fact; waveguide dispersion can be used to counteract material dispersion.

1.4 FIBER CHARACTERISTICS

Mechanical characteristics

1. Strength
2. Static fatigue
3. Dynamic fatigue

1. Strength

The cohesive bond strength of the constituent atoms of a glass fiber governs its theoretical intrinsic strength. Maximum tensile strength of 14 GPa is observed in short length glass fibers. This is closed to the 20 GPa tensile strength of steel wire. The difference between glass and metal is that, under an applied stress. The difference between glass and metal is that, under an applied stess, glass will extend elastically up to its breaking strength whereas metal can be stretched plastically well beyond their elastic range

Eg: Copper wires can be elongated plastically.

2. Static fatigue

It refers to the slow growth of the existing flaws in the glass fiber under humid conditions and tensile stress. This gradual flaw growth causes the fiber to fail at a lower stress level than that which could be reached under a strength test. The flaw shown propagates through the fiber because of chemical erosion of the fiber material at the flaw tip. The primary cause of this erosion is the presence of water in the environment which reduces the strength of SiO_2 bonds in glass. The speed of the growth reaction is increased when the fiber is put under test. Fused silica offers the most resistance of glasses in water. In general, coating are applied to the fiber immediately during the manufacturing process which affords a good degree of protection against environmental corrosion.

3. Dynamic fatigue:

When an optical cable is being installed on a duct, it experiences repeated stress owing to surging effects. The surging is caused by varying degrees of friction between the optical cable and the duct or guiding tool on a curved route. Varying stress also arises in aerial cables that are set into transverse vibration by the wind. Theoritical and experimental investigation have shown that the time to fail under these conditions is related to the maximum allowable stress by the same life time parameter that are in the cases of statics stress that increases at a constant rate.

Transmission characteristics

1. Attenuation

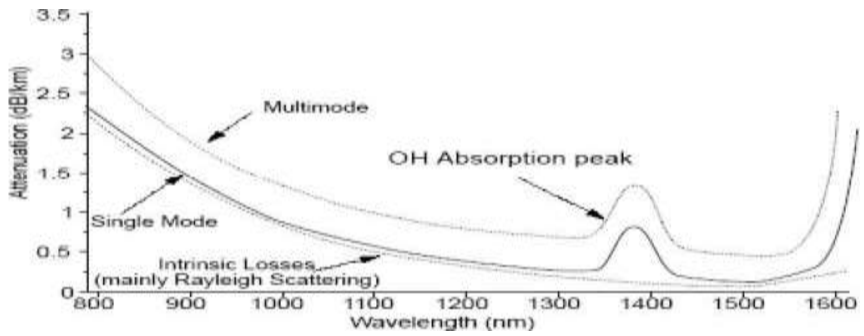

Figure 1.4.1 Fiber Infrared Absorption Spectrum

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 54]

The lower curve shows the characteristics of a single-mode fiber made from a glass containing about 4% of germanium dioxide (GeO2) dopant in the core. The upper curve is for modern graded index multimode fiber. Attenuation in multimode fiber is higher than in single mode because higher levels of dopant are used. The peak at around 1400 nm is due to the effects of traces of water in the glass.

Attenuation in fiber optics, also known as transmission loss, is the reduction in intensity of the light beam with respect to distance travelled through a transmission medium. Attenuation coefficients in fiber optics usually use units of dB/km through the medium due to the relatively high quality of transparency of modern optical transmission media. 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 input power (Pi) to the optical output power (Po).

Optical input power is the power injected into the fiber from an optical source. Optical output power is the power received at the fiber end or optical detector.

$$\text{Attenuation} = (\_\_)\ \log_{10} (\_\_)$$

Each mechanism of loss is influenced by fiber-material properties and fiber structure. However, loss is also present at fiber connections i.e. connector, splice, and coupler losses.

1.8 OPTICAL SOURCES

Light Emitting Diode (LED) Principle:

- It's a device used to convert the electrical energy into light energy.
- When it is forward biased, the majority charge carriers of electrons from n-type and holes from p-type are diffuse into each other.
- At the junction the electron hole recombination process takes place and energy is emitting in the form of visible light and IR region.

Construction:

The light emitting diode is made by Gallium Arsenide semiconductors. First the PN Junction is formed by epitaxial growth technique.

Si+Ga=n-type; Si+As=p-type.

The thickness of the n-layer is always larger than the p-layer, because of increasing the radioactive recombination.

Proper electric connection (forward bias) given to the semiconductor through aluminium contact. P-jn is slightly open for out coming light rays.

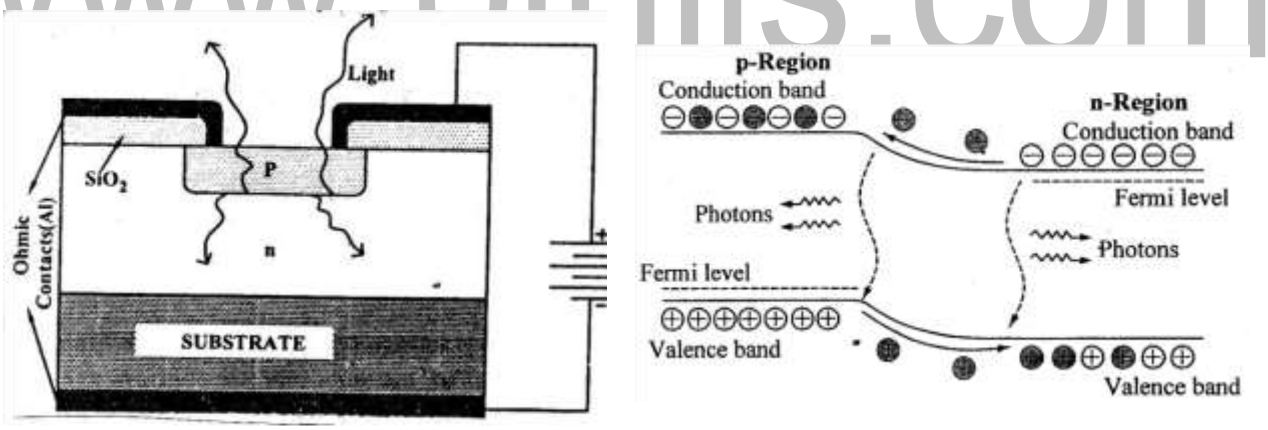

Figure 1.8.1 Structure of Light Emitting Diode

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 182]

Working:

- When the p-n junction diode is forward biased, the barrier width is reduced, raising the potential energy on the n-side and lowering that on the p-side.
  - The free electrons and holes have sufficient energy to move into the junction region. If a free electron meets a hole, it recombines and releases a photon.

- Thus, light radiation from the LED is caused by the recombination of holes and electrons that are injected into the junction by a forward bias voltage.

Advantages of LED

1. Very small in size
2. Less cost and long life time.
3. It needs less voltage for operate

Disadvantages of LED

1. It requires high power.
2. Its preparation cost is high.

PHOTO DETECTORS

PIN Diode Principle:

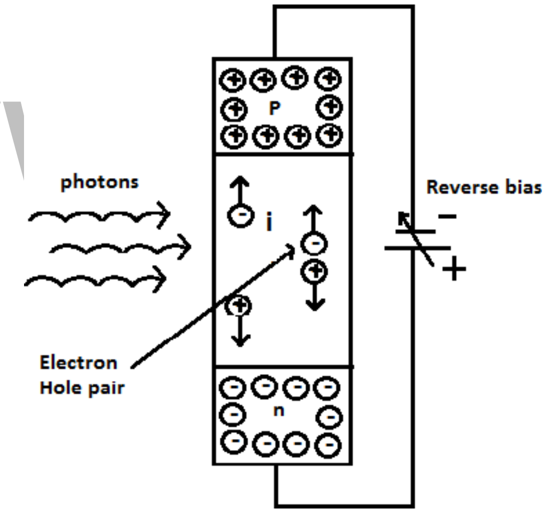

Figure 1.8.2 Structure of PIN Diode

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 184]

This is a device used to convert the light energy into electrical energy.

Under the reverse bias condition, if the light ray is incident over the intrinsic region, then it will produce the electron hole pair. The accelerated electron-hole pair charges carrier produce the photo-current.

Construction:

- It consists of three layers such as p, n and intrinsic region with proper biasing.
- The P and N region are heavily doped.
- The intrinsic layer is slightly larger than both the p- type and n-type for receive the light photons.

Working:

- The PIN diode is heavily reverse biased.
- When a photon of higher energy is incident over the larger width intrinsic semiconductor layer, then the electron hole pairs are created.
- The mobile charges are accelerated by the applied voltage, which gives rise to photo current in the external circuit.
- It is a linear device because the photo-current is directly proportional to the incident optical power on the PIN photo-diode.

1.2 PROCESS OF OPTICAL FIBER COMMUNICATION

A serial bit stream in electrical form is presented to a modulator, which encodes the data appropriately for fiber transmission.

- A light source (laser or Light Emitting Diode - LED) is driven by the modulator and the light focused into the fiber.
- The light travels down the fiber (during which time it may experience dispersion and loss of strength).
- At the receiver end the light is fed to a detector and converted to electrical form.
- The signal is then amplified and fed to another detector, which isolates the individual state changes and their timing. It then decodes the sequence of state changes and reconstructs the original bit stream.
- The timed bit stream so received may then be fed to a using device

Principle of light propagation through a fibre

- Total internal reflection
- Acceptance angle (θ_a)
- Numerical aperture.
- Skew mode.

Total internal reflection.

i) Index of refraction:

This is the measuring speed of light in respective medium. It is calculated by dividing speed of light in vacuum to the speed of light in material. The RI for vacuum is 1, for the cladding material of optical fiber it is 1.46, the core value of RI is 1.48(core RI must be more than cladding material RI for transmission. it means signal will travel around 200 million meters per second. it will 12000 km in only 60 seconds, other delay in communication will be due to communication equipment switching and decoding, encoding the voice of the fiber.

ii) Snell's law :

In order to understand ray propagation in a fiber. This is called Snell's Law.

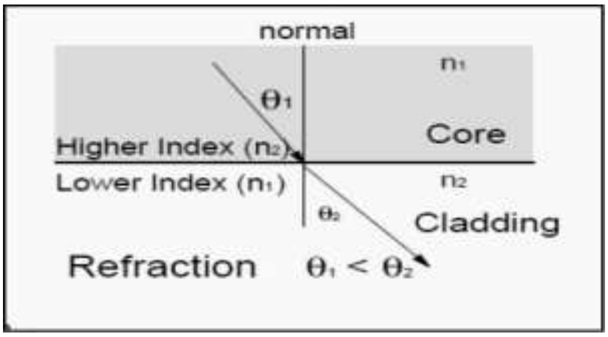

Figure 1.2.1 Ray Propagation in Fibre

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 21]

$$n_1 \sin .0_1 = n_2 \sin .0_2$$

Where n denotes the refractive index of material. $0_1/0_2$ is angles in respective medium. Higher refractive index means denser medium.

1 When light enters in lighter medium from denser medium it inclines towards normal.
2 When light enters in denser medium from lighter medium it inclines to normal.

Critical Angle

If we consider we notice above that as angle 01 becomes larger and larger so does angle 02. Because of the refraction effect 02 becomes large more quickly than 01. At the same point 02 will reach 90° while 01 is still well less than that. This is called "critical angle". When 01 increase further then refraction ceases and the light starts to be reflected rather than refracted. Thus light is perfectly reflected at an interface between two materials of different refractive index if:

Total Internal Reflection (TIR)

When light traveling in a dense medium hits a boundary at a steep angle (larger than the "critical angle "for the boundary), the light will be completely reflected. This phenomenon is called total internal reflection. This effect is used in optical fibers to confine light in the core. Light travels along the fiber bouncing back and forth off of the boundary; because the light must strike the boundary with an angle greater than the critical angle, possible in air to glass. If we now consider above Figures we can see the effect of the critical only light that enters the fiber certain range of angles can travel down the fiber without leaking out. Total internal reflection occurs when light enters from higher refractive index to lower refractive index material, i.e. from glass to air total internal reflection is possible but it is not possible in air to glass.

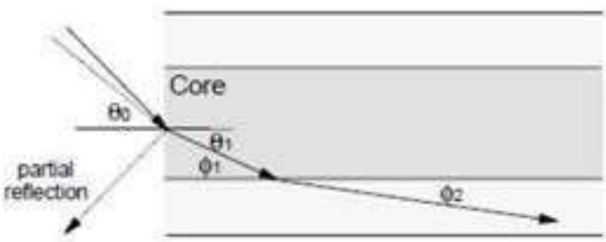

Figure 1.2.2 Optical Rays Leaks out from Core

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 27]

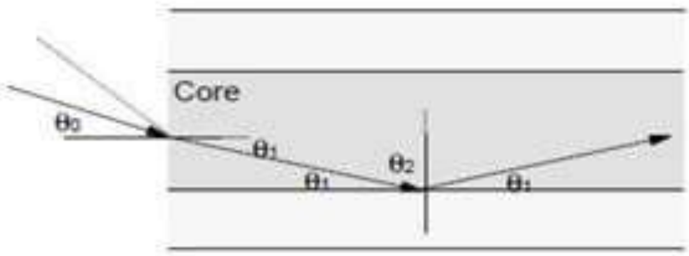

Figure 1.2.3 Optical Rays Reflected back due to TIR

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 27]

we see that for rays where angle 01 less than a critical value then the ray will propagate along the fiber and will be bound within the fiber. In fig. 1 we see that where the angle 01 is greater than critical value the ray is refracted into the cladding and will ultimately be lost outside the fiber. This is loss.

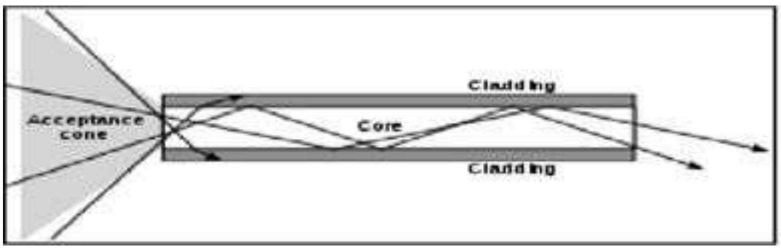

Figure 1.2.4 Acceptance Cone

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 28]

Acceptance angle (θ_a)

The maximum incident angle below which the ray undergoes the total internal reflection is called an acceptance angle. The cone is referred as acceptance cone. When we consider rays entering the fiber from the outside (into the end face of fiber) we see that there is a further complication. The refractive index difference between the fiber core and the air will cause any arriving ray to be refracted. This means that there is a maximum angle for a ray arriving at the fiber end face at which the ray will propagate. Rays arriving at an angle less than this angle will propagate but rays arriving at greater angle will not. This angle is not a "critical angle" as that term is reserved for the case where light arrives from a material of higher RI to one of lower RI (In this, case the critical angle is the angle within the fiber). Thus there is "cone of acceptance" at the endface of a fiber. Rays arriving within the cone will propagate and ones arriving outside of it will not. The acceptance cone is function of difference of RI of core and cladding

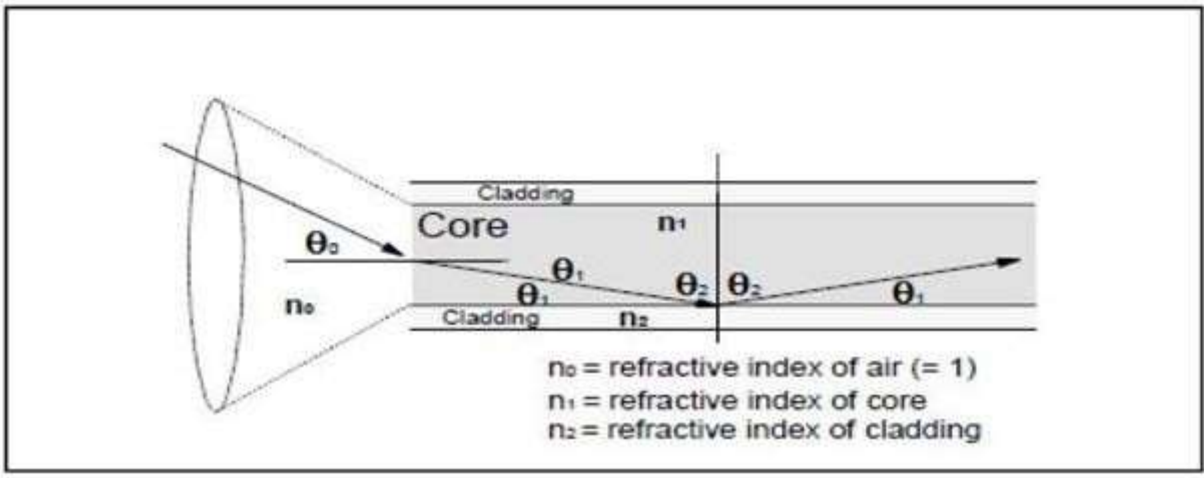

Figure 1.2.5 Numerical Aperture

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 29]

Numerical aperture (NA)

It is defined as the sine of acceptance angle of the fiber.

i.e. NA = Sin i_{max} =

One of the most often quoted characteristics of an optical fiber is its "Numerical Aperture". The NA is intended as a measure of the light capturing ability of the fiber.

However it is used for many other purposes. For example it may be used as a measure of the amount of loss that we might expect on a bend of a particular radius etc. This ray will be refracted and will later encounter the core-cladding interface at an angle such that it will be reflected. This is because the angle 02 is greater than the critical angle. The angle is greater because we are measuring angle from a normal to the core-cladding boundary not a tangent to it.

This one will reach the core- cladding interface at an angle smaller than the critical angle it will pass into the cladding. This ray will eventually be lost. It is clear that there is a "cone" of acceptance If ray enters the fiber at an angle within the cone then it will be captured and propagates as a bound mode. If a ray enters the fiber at an angle outside the cone then it will leave the core and eventually leave the fiber itself. The Numerical Aperture is the sign of the largest angle contained within the cone of acceptance.

An expression for an Acceptance angle and Numerical aperture

Let us consider an optical fiber, where n_0=Refractive Index of Air; n_1 = Refractive Index of Core; n_2 = Refractive Index of Cladding.

- The ray AO enter from air into core at an incident angle 'i' Refract thro OBat an angle 'θ'
- Finally, it is incident from core to cladding surface at an angle ϕ_C.
- At the incident angle is critical angle (ϕ_C), the ray just moves along interface BC.

Hence, the angle of incidence ($\phi_C = 90 - \theta$) at the interface of core and cladding will be more than the critical angle. Hence the ray is totally internally reflected ray.

Thus, only those ray which passes within the acceptance angle will be totally internally reflected. Therefore, the light incident on the core within this maximum external incident angle can be coupled into the fiber to propagate. This angle is called as an acceptance angle.

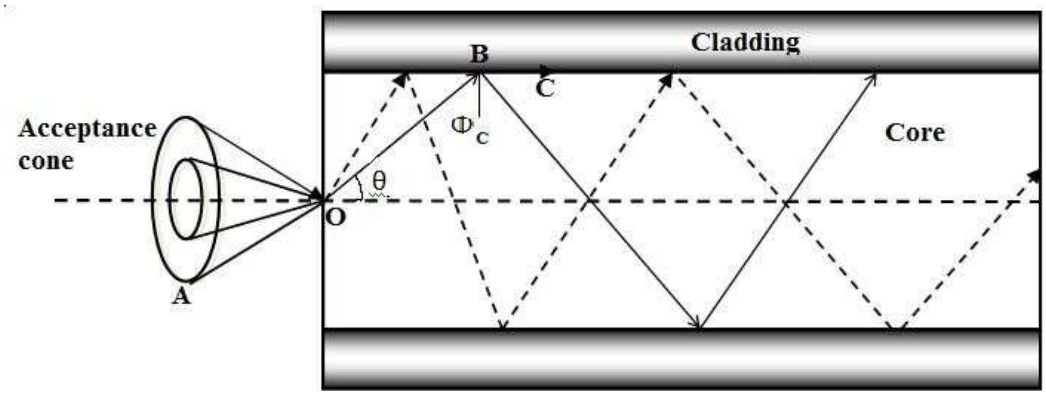

Figure 1.2.6 Acceptance Angle

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 28]

1.3.4. Skew mode

The rays follows a helical path through the fiber is called skew ray. The light traveling down the fiber is a group of electromagnetic (EM) waves occupying a small band of frequencies within the electromagnetic spectrum, so it is a simplification to call it a ray of light. However, it is enormously helpful to do this, providing an easy concept, some framework to hang our ideas on. We do this all the time and it serves us well providing we are clear that it is only an analogy. Magnetic fields are not really lines floating in space around a magnet, electrons are not really little black ball bearings flying round a red nucleus. Light therefore, is propagated as an electromagnetic wave along the fiber. The two components, the electric field and the magnetic field form patterns across the fiber. These patterns are called modes of transmission.

Modes means methods — hence methods of transmission. An optic fiber that carries more than one mode is called a multimode fiber (MM). The number of modes is always a whole number. In a given piece of fiber, there are only a set number of possible modes. This is because each mode is a pattern of electric and magnetic fields having a physical size. The dimensions of the core determine how many modes or patterns can exist in the core — the larger the core, the more modes. The number of modes is always an integer, we cannot have incomplete field patterns. This is similar to transmission of motor vehicles along a road. As the road is made wider, it stays as a single lane road until it is large enough to accommodate an extra line of vehicles whereupon it suddenly jumps to a two lane road. We never come across a 1.15 lane road.