OPTICAL FIBER COMMUNICATION

1.1. Historical Development

- Fiber optics deals with study of propagation of light through transparent dielectric waveguides. The fiber optics are used for transmission of data from point to point location. Fiber optic systems currently used most extensively as the transmission line between terrestrial hardwired systems.
- The carrier frequencies used in conventional systems had the limitations in handling the volume and rate of the data transmission. The greater the carrier frequency larger the available bandwith and information carrying capacity.

Need of fiber optic communication

- Fiber optic communication system has emerged as most important communication system. Compared to traditional system because of following requirements:

  1. In long haul transmission system, there is need of low loss transmission medium
  2. There is need of compact and least weight transmitters and receivers.
  3. There is need of increase span of transmission.
  4. There is need of increased bit rate-distance product.

- A fiber optic communication system fulfills these requirements, hence most widely accepted.

1.2 General Optical Fiber Communication System

- Basic block diagram of optical fiber communication system consists of following important blocks.
  1. Transmitter 2.
  Information channel 3.
  Receiver.

Fig. 1.2.1 shows block diagram of OFC system.

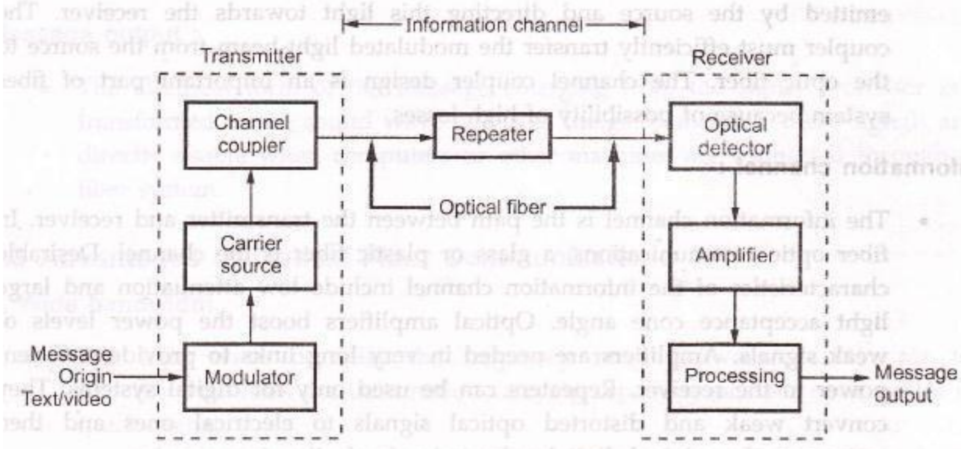

Fig. 1.2.1 Block diagram of OFC systems

Message origin:

- Generally, message origin is from a transducer that converts a non-electrical message into an electrical signal. Common examples include microphones for converting sound waves into currents and video (TV) cameras for converting images into current. For data transfer between computers, the message is already in electrical form. **Modulator:**

- The modulator has two main functions. 1) It converts the electrical message into the proper format.

  2) It impresses this signal onto the wave generated by the carrier source.

  Two distinct categories of modulation are used i.e. analog modulation and digital modulation.

Carrier source:

- Carrier source generates the wave on which the information is transmitted. This wave is called the carrier. For fiber optic system, a laser diode (LD) or a light emitting diode (LED) is used. They can be called as optic oscillators, they provide stable, single frequency waves with sufficient power for long distance propagation.

Channel coupler:

- Coupler feeds the power into the information channel. For an atmospheric optic system, the channel coupler is a lens used for collimating the light emitted by the source and directing this light towards the receiver. The coupler must efficiently transfer the modulated light beam from the source to the optic fiber. The channel coupler design is an important part of fiber system because of possibility of high losses. **Information channel:**

- The information channel is the path between the transmitter and receiver. In fiber optic communications, a glass or plastic fiber is the channel. Desirable characteristics of the information channel include low attenuation and large light acceptance cone angle. Optical amplifiers boost the power levels of weak signals. Amplifiers are needed in very long links to provide sufficient power to the receiver. Repeaters can be used only for digital systems. They convert weak and distorted optical signals to electrical ones and then regenerate the original disgital pulse trains for further transmission.

- Another important property of the information channel is the propagation time of the waes travelling along it. A signal propagating along a fiber normally contains a range of optic frequencies and divides its power along several ray paths. This results in a distortion of the propagating signal. In a digital system, this distortion appears as a spreading and deforming of the pulses. The spreading is so great that adjacent pulses begin to overlap and become unrecognizable as separate bits of information. **Optical detector:**

- The information being transmitted is detector. In the fiber system the optic wave is converted into an electric current by a photodetector. The current developed by the detector is proportional to the power in the incident optic wave. Detector output current contains the transmitted information. This detector output is then filtered to remove the constant bias and the amplified.

- The important properties of photodetectors are small size, economy, long life, low power consumption, high sensitivity to optic signals and fast response to quick variations in the optic power.

Signal processing:

- Signal processing includes filtering, amplification. Proper filtering maximizes the ratio of signal to unwanted power. For a digital system decision circuit is an additional block. The bit error rate (BER) should be very small for quality communications. **Message output:**

- The electrical form of the message emerging from the signal processor are transformed into a sound wave or visual image. Sometimes these signals are directly usable when computers or other machines are connected through a fiber system.

1.3 Advantages of Optical Fiber Communications

1. Wide bandwidth

- The light wave occupies the frequency range between 2×10^{12} Hz to 3.7×10^{12} Hz. Thus, the information carrying capability of fiber optic cables is much higher.

2. Low losses

- Fiber optic cables offers very less signal attenuation over long distances. Typically, it is less than 1 dB/km. This enables longer distance between repeaters.

3. Immune to cross talk

- Fiber optic cables has very high immunity to electrical and magnetic field. Since fiber optic cables are non-conductors of electricity hence, they do not produce magnetic field. Thus fiber optic cables are immune to cross talk between cables caused by magnetic induction.

4. Interference immune

- Fiber optic cables are immune to conductive and radiative interferences caused by electrical noise sources such as lighting, electric motors, fluorescent lights.

5. Light weight

- As fiber cables are made of silica glass or plastic which is much lighter than copper or aluminum cables. Light weight fiber cables are cheaper to transport.

6. Small size

- The diameter of fiber is much smaller compared to other cables, therefore fiber calbe is small in size, requires less storage space.

7. More strength

- Fiber cables are stronger and rugged hence can support more weight.

8. Security

- Fiber cables are more secure than other cables. It is almost impossible to tap into a fiber cable as they do n ot radiate signals.

No ground loops exist between optical fibers hence they are more secure.

9. Long distance transmission

- Because of less attenuation transmission at a longer distance is possible.

10. Environment immune

- Fiber cables are more immune to environmental extremes. They can operate over a large temperature variation. Also, they are not affected by corrosive liquids and gases.

11. Sage and easy installation

- Fiber cables are safer and easier to install and maintain. They are non-conductors hence there is no shock hazards as no current or voltage is associated with them. Their small size and light weight feature make installation easier.

12. Less cost

- Cost of fiber optic system is less compared to any other system.

1.4 Disadvantages of Optical Fiber Communications

1. High initial cost

- The initial cost of installation or setting up cost is very high compared to all other system.

2. Maintenance and repairing cost

- The maintenance and repairing of fiber optic systems is not only difficult but expensive also.

3. Jointing and test procedures

- Since optical fibers are of very small size. The fiber joining process is very costly and requires skilled manpower.

4. Tensile stress

- Optical fibers are more susceptible to buckling, bending and tensile stress than copper cables. This leads to restricted practice to use optical fiber technology to premises and floor backbones with a few interfaces to the copper cables.

5. Short links

- Even though optical fiber cables are inexpensive, it is still not cost effective to replace every small conventional connector (e.g. between computers and peripherals), as the price of optoelectronic transducers are very high.

6. Fiber losses

- The amount of optical fiber available to the photodetector at the end of fiber length depends on various fiber losses such as scattering, dispersion, attenuation and reflection.

1.5 Applications of Optical Fiber Communications

- Applications of optical fiber communications include telecommunications, data communications, video control and protection switching, sensors and power applications.

1. Telephone networks

- Optical waveguide has low attenuation, high transmission bandwidth compared to copper lines, therefore numbers of long haul co-axial trunks links between telephone exchanges are being replaced by optical fiber links.

2. Urban broadband service networks

- Optical waveguide provides much larger bandwidth than co-axial cables, also the number of repeaters required is reduced considerably.

- Modern suburban communications involve videotext, videoconferencing videotelephony, switched broadband communication network. All these can be supplied over a single fiber optic link. Fiber optic cables is the solution to many of today’s high speed, high bandwidth data communication problems and will continue to play a large role in future telecom and data-com networks.

1.6 Optical Fiber Waveguides

- In free space light travels as its maximum possible speed i.e. 3×10^8 m/s or 186×10^3 miles/sec. When light travels through a material it exhibits certain behavior explained by laws of reflection, refraction.

Electromagnetic Spectrum

- The radio waves and light are electromagnetic waves. The rate at which they alternate in polarity is called their frequency (f) measured in hertz (Hz). The speed of electromagnetic wave (c) in free space is approximately 3×10^8 m/sec. The distance travelled during each cycle is called as wavelength (λ)

$$\text{Wavelength } (\lambda) = \frac{\text{Speed of light}}{\text{Frequency}} = \frac{c}{f}$$

- In fiber optics, it is more convenient to use the wavelength of light instead of the frequency with light frequencies, wavelength is often stated in microns or nanometers.

1 micron (μ) = 1 Micrometer (1×10^{-6})

1 nano (n) = 10^{-9} meter

Fig. 1.6.1 shows electromagnetic frequency spectrum.

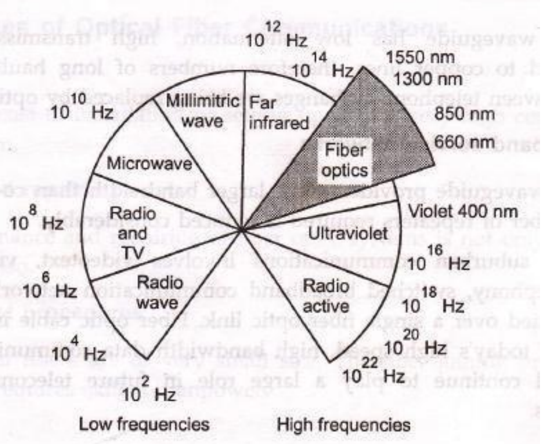

Fig. 1.6.1 Electromagnetic spectrum

- Fiber optics uses visible and infrared light. Infrared light covers a fairly wide range of wavelengths and is generally used for all fiber optic communications. Visible light is normally used for very short-range transmission using a plastic fiber.

Ray Transmission Theory

- Before studying how the light actually propagates through the fiber, laws governing the nature of light m ust be studied. These was called as **laws of optics (Ray theory).** There is conception that light always travels at the same speed. This fact is simply not true. The speed of light depends upon the material or medium through which it is moving. In free space light travels at its maximum possible speed i.e. 3 x 108 m/s or 186 x 103 miles/sec. When light travels through a material it exhibits certain behavior explained by laws of reflection, refraction.

Reflection

- The law of reflection states that, when a light ray is incident upon a reflective surface at some incident angle $\square_1$ from imaginary perpendicular normal, the ray will be reflected from the surface at some angle $\square_2$ from normal which is equal to the angle of incidence. Fig. 1.6.2 shows law of relection.

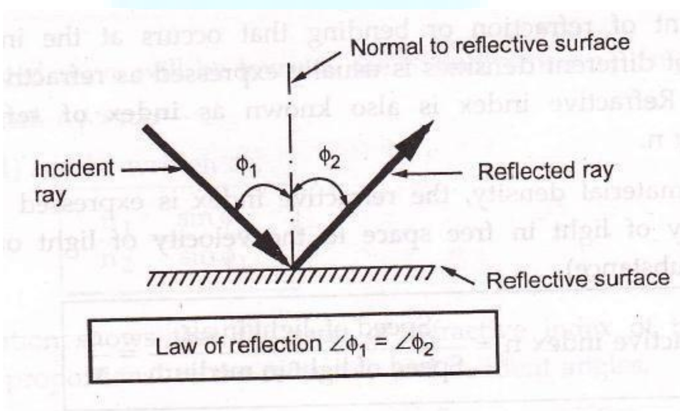

Fig. 1.6.2 Reflection

Refraction

- Refraction occurs when light ray passes from one medium to another i.e. the light ray changes its direction at interface. Refraction occurs whenever density of medium changes. E.g. refraction occurs at air and water interface, the straw in a glass of water will

appear as it is bent. The refraction can also observed at air and glass interface.

- When wave passes through rarer to denser medium, the wave is refracted (bent) towards the normal. Fig. 1.6.3 shows the refraction phenomena.

- The refraction (bending) takes place because light travels at different speed in different mediums. The speed of light in free space is higher than in water or glass.

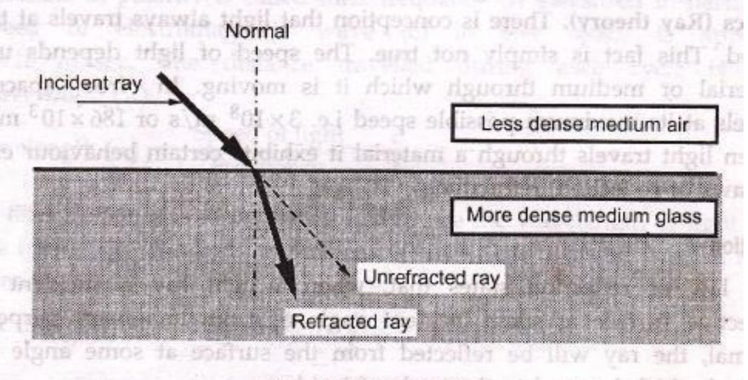

Fig. 1.6.3 Refraction

Refractive Index

- The amount of refraction or bending that occurs at the interface of two materials of different densities is usually expressed as refractive index of two materials. Refractive index is also known as **index of refraction** and is denoted by n.

- Based on material density, the refractive index is expressed as the ratio of the velocity of light in free space to the velocity of light of the dielectric material (substance).

$$\text{Refractive index } n = \frac{\text{Speed of light in air}}{\text{Speed of light in medium}} = \frac{c}{v}$$

The refractive index for vacuum and air is 1.0 for water it is 1.3 and for glass refractive index is 1.5.

Snell's Law

- Snell's law states how light ray reacts when it meets the interface of two media having different indexes of refraction.

- Let the two medias have refractive indexes n1 and n_2 where $n_1 > n_2$.

□1 and □2 be the angles of incidence and angle of refraction respectively. Then according to Snell's law, a relationship exists between the refractive index of both materials given by,

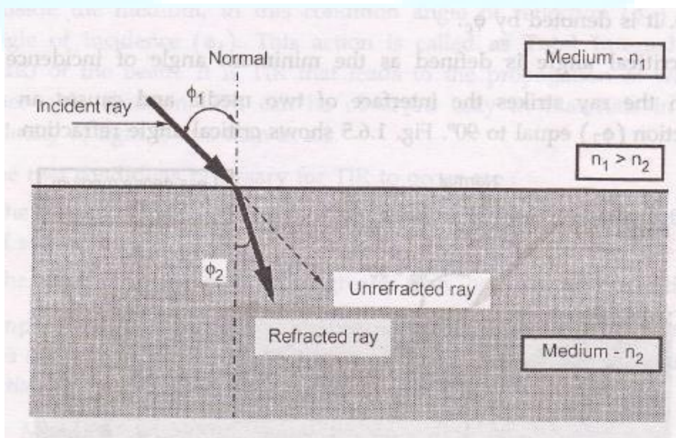

Fig. 1.6.4 Refractive model for Snell's law

Refractive model for Snell's Law

$$n_1 \sin \phi_1 = n_2 \sin \phi_2 \text{ ....(1.6.1)}$$

- **Refracted wave will be towards the normal when $n_1 < n_2$ and will away from it when $n_1 > n_2$.**

Equation (1.6.2) can be written as,

$$\frac{n_1}{n_2} = \frac{\sin \emptyset_2}{\sin \emptyset_1}$$

- **This equation shows that the ratio of refractive index of two mediums is inversely proportional to the refractive and incident angles.**

As refractive index $n_1 = \frac{c}{v_1}$ and $n_2 = \frac{c}{v_2}$

substituting these values in equation (1.6.2)

$$\frac{c / v_1}{c / v_2} = \frac{\sin \phi_2}{\sin \phi_1}$$

$$\frac{v_2}{v_1} = \frac{\sin \phi_2}{\sin \phi_1}$$

Critical Angle

- When the angle of incidence ($\square_1$) is progressively increased, there will be progressive increase of refractive angle ($\square_2$). At some condition ($\square_1$) the refractive angle ($\square_2$) becomes 90^o to the normal. When this happens the refracted light ray travels along the interface. The angle of incidence ($\square_1$) at the point at which the refractive angle ($\square_1$) becomes 90^o is called the critical angle. It is denoted by $\square_c$.

- The **critical angle** is defined as the minimum angle of incidence ($\square_1$) at which the ray strikes the interface of two media and causes an angle of refraction ($\square_2$) equal to 90^o. Fig 1.6.5 shows critical angle refraction.

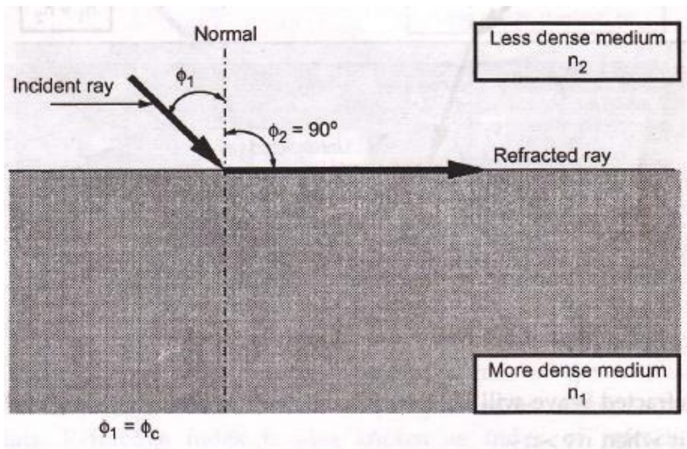

Fig. 1.6.5 Critical angle

Hence at critical angle $\phi_1 = \phi_c$ and $\phi_2 = 90^o$ Using

Snell's law : $n_1 \sin \phi_1 = n_2 \sin \phi_2$

$$\sin \phi_c = \frac{n_2}{n_1} \sin 90^o$$

$\because$ $$\sin 90^o = 1$$

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

Therefore,

$$\boxed{\text{Critical angle } \phi_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)} \quad \ldots (1.6.3)$$

- The actual value of critical angle is dependent upon combination of materials present on each side of boundary.

Total Internal Reflection (TIR)

- When the incident angle is increased beyond the critical angle, the light ray does not pass through the interface into the other medium. This gives the effect of mirror exist at the interface with no possibility of light escaping outside the medium. In this condition angle of reflection (ϕ_2) is equal to angle of incidence (ϕ_1). This action is called as **Total Internal Reflection (TIR)** of the beam. It is TIR that leads to the propagation of waves within fibercable medium. TIR can be observed only in materials in which the velocity of light is less than in air.

- The two conditions necessary for TIR to occur are:

1. The refractive index of first medium must be greater than the refractive index of second one.
2. The angle of incidence must be greater than (or equal to) the critical angle.

Example 1.6.1 : A light ray is incident from medium-1 to medium-2. If the refractive indices of medium-1 and medium-2 are 1.5 and 1.36 respectively then determine the angle of refraction for an angle of incidence of 30°.

Solution : Medium-1 $n_1 = 1.5$

Medium-2 $n_2 = 1.36$ Angle

of incidence $\phi_1 = 30^o$.

Angle of incident ϕ_2 = ?

Snell's law : $n_1 \sin \phi_1 = n_2 \sin \phi_2$

$$1.5 \sin 30^o = 1.36 \sin \phi_2$$

$$\sin \phi_2 = \frac{1.5}{1.36} \sin 30^o$$

$$\sin\phi_2 = 0.55147$$

$\therefore$ $$\phi_2 = 33.46^\circ$$

Angle of refraction 33.46° from normal. **… Ans.**

Example 1.6.2 : A light ray is incident from glass to air. Calculate the critical angle ($\square_c$).

Solution : Refractive index of glass $n_1 = 1.50$

Refrative indes of air $n_2 = 1.00$

Snell'slaw : $n_1 \sin\phi_1 = n_2 \sin\phi_2$

$$\sin\phi_1 = \frac{n_2}{n_1}\sin\phi_2$$

From definition of critical angle, $\square_2 = 90^\circ$ and $\square_1 = \square_c$.

$\therefore$ $$\sin\phi_1 = \frac{n_2}{n_1}\sin 90^\circ$$

$$\sin\phi_c = \left(\frac{1.0}{1.5}\right) x\, 1 = 0.67$$

$\therefore$ $$\phi_c = \sin^{-1} 0.67$$

$$\phi_c = 41.81^\circ$$

Critical angle $\phi_c = \mathbf{41.81^\circ}$

… Ans.

Optical Fiber as Waveguide

- An optical fiber is a cylindrical dielectric waveguide capable of conveying electromagnetic waves at optical frequencies. The electromagnetic energy is in the form of the light and propagates along the axis of the fiber. The structural of the fiver determines the transmission characteristics.

- The propagation of light along the waveguide is decided by the modes of the waveguides, here mode means path. Each mode has distinct pattern of electric and magnetic field distributions along the fiber length. Only few modes can satisfy the homogeneous wave equation in the fiver also the boundary condition a waveguide surface. When there is only one path for light to follow then it is called as single mode propagation. When there is more than one path then it is called as multimode propagation.

Single fiber structure

- A single fiber structure is shown in Fig. 1.6.6. It consists of a solid dielectric cylinder with radius ‘a’. This cylinder is called as **core** of fiber. The core is surrounded by dielectric, called **cladding**. The index of refraction of core (glass fiber) is slightly greater than the index of refraction of cladding. If refractive index of core (glass fiver) = n_1 and refractive index of cladding = n_2

then $n_1 > n_2$.

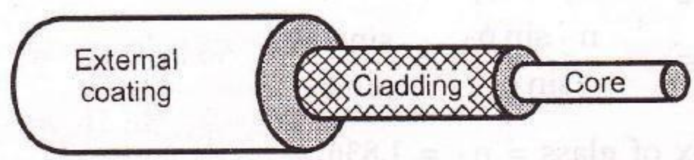

Fig. 1.6.6 Single optical fiber structure

Propagation in Optical Fiber

- To understand the general nature of light wave propagation in optical fiber. We first consider the construction of optical fiber. The innermost is the glass core of very thin diameter with a slight lower refractive index n2. The light wave can propagate along such a optical fiber. A single mode propagation is illustrated in Fig. 1.6.7 along with standard size of fiber.

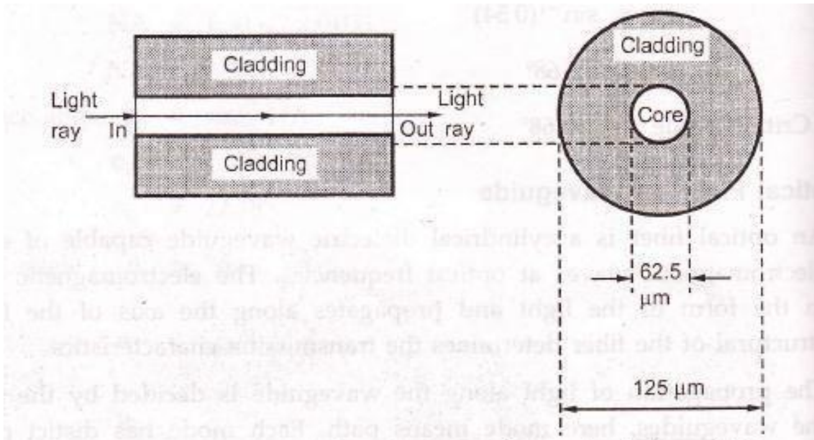

Fig. 1.6.7 Single mode propagation and standard size of fiber

- Single mode fibers are capable of carrying only one signal of a specific wavelength.
- In multimode propagation the light propagates along the fiber in zigzag fashion, provided it can undergo total internal reflection (TIR) at the core cladding boundaries.
- Total internal reflection at the fiber wall can occur only if two conditions are satisfied.

Condition 1:

The index of refraction of glass fiber must be slightly greater than the index of refraction of material surrounding the fiber (cladding). If refractive index of glass fiber = n_1 and refractive index of cladding = n_2 then $n_1 > n_2$. **Condition 2 :**

The angle of incidence ($\square_1$) of light ray must be greater than critical angle ($\square_c$).

- A light beam is focused at one end of cable. The light enters the fibers at different angles. Fig. 1.6.8 shows the conditions exist at the launching end of optic fiber. The light source is surrounded by air and the refractive index of air is $n_0 = 1$. Let the incident ray makes an angle $\square_0$ with fiber axis. The ray enters into glass fiber at point P making refracted angle $\square_1$ to the fiber axis, the ray is then propagated diagonally down the core and reflect from the core wall at point Q. When the light ray reflects off the inner surface, the angle of incidence is equal to the angle of reflection, which is greater than critical angle.

- In order for a ray of light to propagate down the cable, it must strike the core cladding interface at an angle that is greater than critical angle (ϕ_c).

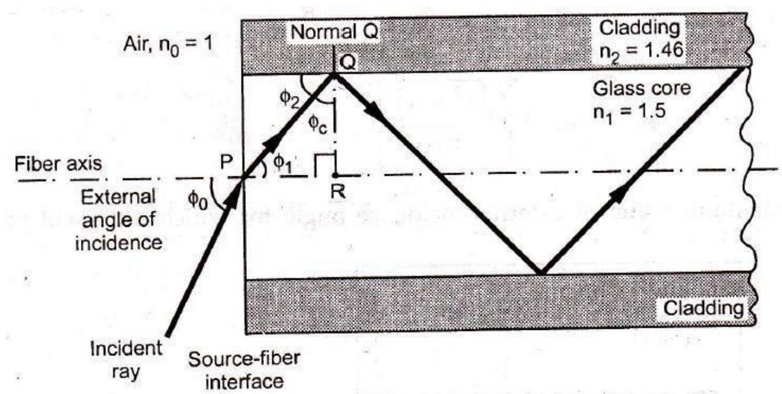

Fig. 1.6.8 Ray propagation by TIR

Acceptance Angle

Applying Snell's law to external incidence angle.

$$n_0 \sin \phi_0 = n_1 \sin \phi_1 \quad \text{........................} (A)$$

But $\phi_1 = (90 - \phi_c)$

$$\sin \phi_1 = \sin (90 - \phi_c) = \cos \phi_c \quad \text{..................................} (1)$$

Since $\sin \emptyset_c = \frac{n_2}{n_1}$

Applying Pythagorean theorem to ΔPQR.

$$\cos\phi_c = \frac{\sqrt{n_1^2 - n_2^2}}{n_1}$$

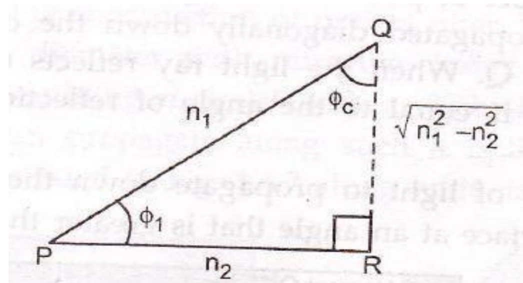

Fig. 1.6.9

Substituting $\sin\phi_1$ from eq (1) to eq (A): n_0

$$\sin\phi_0 = n_1 \cos\phi_c$$

$$\sin\phi_0 = \mathbf{(n_1/n_0)\cos\phi_c}$$

Using the value of $\cos\phi_c$ from above, we have

$$\sin\phi_0 = \frac{n_1}{n_0}\left[\frac{\sqrt{n_1^2 - n_2^2}}{n_1}\right]$$

$$\phi_0 = \sin^{-1}\left[\frac{\sqrt{n_1^2 - n_2^2}}{n_0}\right]$$

$$\sin\phi_0 = \left[\frac{\sqrt{n_1^2 - n_2^2}}{n_0}\right]$$

The maximum value of external incidence angle for which light will propagate in the fiber.

$$\phi_{0(max)} = \sin^{-1}\left[\frac{\sqrt{n_1^2 - n_2^2}}{n_0}\right]$$

When the light rays enters the fivers from an air medium $n_0 = 1$. Then above equation reduces to,

$$\phi_{0(max)} = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$$

The angle □$_0$ is called as **acceptance angle** and $\phi_{0(max)}$ defines the maximum angle in which the light ray may incident on fiber to propagate down the fiber.

Acceptance Cone

- Rotating the acceptance angle $\phi_{0(max)}$ around the fiber axis, a cone shaped pattern is obtained, it is called as **acceptance cone** of the fiber input. Fig 1.6.10 shows formation of acceptance cone of a fiber cable.

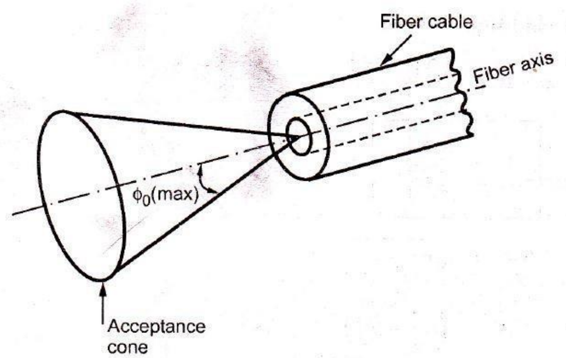

Fig. 1.6.10 Acceptance cone of a fiber cable

- The Cone of acceptance is the angle within which the light is accepted into the core and is able to travel along the fiber. The launching of light wave becomes easier for large acceptance come.
- The angle is measured from the axis of the positive cone so the total angle of convergence is actually twice the stated value.

Numerical Aperture (NA)

- The **numerical aperture** (NA) of a fiber is a figure of merit which represents its light gathering capability. Larger the numerical aperture, the greater the amount of light accepted by fiber. The acceptance angle also determines how much light is able to be enter the fiber and hence there is relation between the numerical aperture and the cone of acceptance.

Numerical aperture (NA) = sin $\phi_{0(max)}$

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

For air $n_o = 1$

$$\therefore \quad NA = \sqrt{n_1^2 - n_2^2}$$

$$\boxed{NA = \sqrt{n_{core}^2 - n_{cladding}^2}}$$

Acceptance angle = $\sin^{-1}$ (NA)

By the formula of NA note that the numerical aperture is effectively dependent only on refractive indices of core and cladding material. NA is not a function of fiber dimension.

- The index difference (Δ) and the numerical aperture (NA) are related to the core and cladding indices:

$$\Delta = \frac{(n_1 - n_2)}{n_1} \qquad (1.6.5\ (a))$$

$$\boxed{\Delta = \frac{NA^2}{2n_1^2}} \qquad \ldots\ (1.6.5\ (b))$$

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

$$NA = (n_1^2 - n_2^2)^{1/2}$$

$$\boxed{NA = n_1 (2\Delta)^{1/2}}$$

Example 1.6.5 : Calculate the numerical aperture and acceptance angle for a fiber cable of which $n_{core} = 1.5$ and $n_{cladding} = 1.48$. The launching takes place from air.

Solution :

$$\boxed{NA = \sqrt{n_{core}^2 - n_{cladding}^2}}$$

$$NA = \sqrt{1.5^2 - 1.48^2}$$

NA = **0.244** **…Ans.**

Acceptance angle - $sin^{-1}\sqrt{n_{core}^2 - n_{cladding}^2} = sin^{-1}$ NA

Acceptance angle = $\sin^{-1}$ 0.244

θ_0 = **14.12º** **…Ans.**

Step Index (SI) Fiber

- The step index (SI) fiber is a cylindrical waveguide core with central or inner core has a uniform refractive index of n_1 and the core is surrounded by outer cladding with uniform refractive index of n_2. The cladding refractive index (n_2) is less than the core refractive index (n_1). But there is an abrupt change in the refractive index at the core cladding interface. Refractive index profile of step indexed optical fiber is shown in Fig.

1.6.13. The refractive index is plotted on horizontal axis and radial distance from the core is plotted on vertical axis.

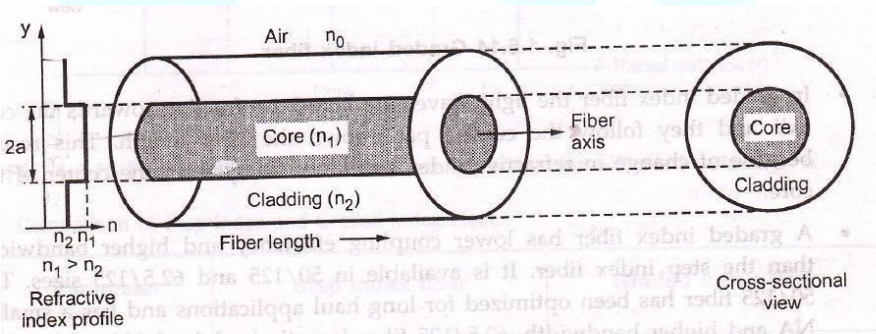

Fig. 1.6.13 Step index fiber

- The propagation of light wave within the core of step index fiber takes the path of meridional ray i.e. ray follows a zig-zag path of straight line segments.

The core typically has diameter of 50-80 µm and the cladding has a diameter of 125 µm.

- The refractive index profile is defined as –

$$n(r) = \begin{cases} n_1 & \text{when } r < a \text{ (core)} \\ n_2 & \text{when } r \geq a \text{ (cladding)} \end{cases}$$

Graded Index (GRIN) Fiber

- The graded index fiber has a core made from many layers of glass.
- In the **graded index (GRIN)** fiber the refractive index is not uniform within the core, it is highest at the center and decreases smoothly and continuously with distance towards the cladding. The refractive index profile across the core takes the parabolic nature. Fig. 1.6.14 shows refractive index profile of graded index fiber.

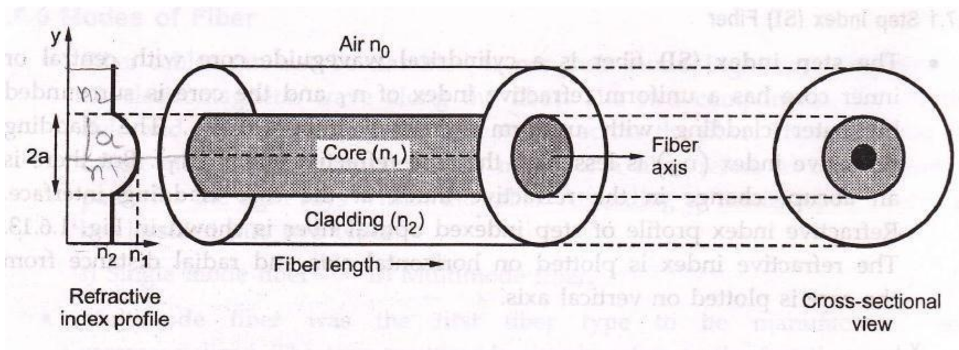

Fig. 1.6.14 Graded index fiber

- In graded index fiber the light waves are bent by refraction towards the core axis and they follow the curved path down the fiber length. This results because of change in refractive index as moved away from the center of the core.
- A graded index fiber has lower coupling efficiency and higher bandwidth than the step index fiber. It is available in 50/125 and 62.5/125 sizes. The 50/125 fiber has been optimized for long haul applications and has a smaller NA and higher bandwidth. 62.5/125 fiber is optimized for LAN applications which is costing 25% more than the 50/125 fiber cable.
- The refractive index variation in the core is giver by relationship

$$n(r) = \begin{cases} n_1\left(1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right) & \text{when } r < a \ (core) \\ n_1(1 - 2\Delta)^{\frac{1}{2}} \approx n_2 & when\ r \geq a \ \text{(cladding)} \end{cases}$$

where, r = Radial distance from fiber axis

a = Core radius n_1 = Refractive index of core n_2 = Refractive

index of cladding α = Shape of
index profile.

- Profile parameter α determines the characteristic refractive index profile of fiber core. The range of refractive index as variation of α is shown in Fig. 1.6.15.

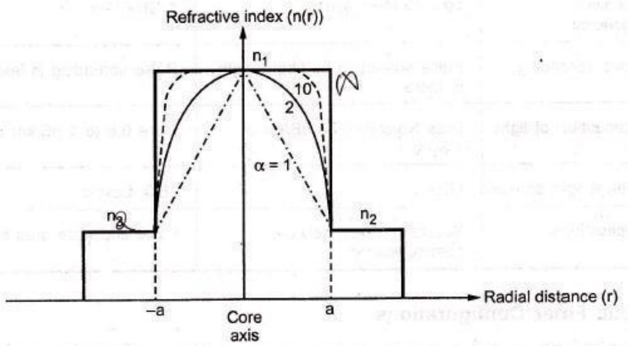

Fig. 1.6.15 Possible fiber refractive index profiles for different values of α

Comparison of Step Index and Graded Index Fiber

Sr. No.	Parameter	Step index fiber	Graded index fiber
1.	Data rate	Slow.	Higher
2.	Ray path	By total internal reflection.	Light ray travels in oscillatory fashion.
3.	Numerical aperture	NA remains same.	Changes continuously with distance from fiber axis.
4.	Material used	Normally plastic or glass is preferred.	Only glass is preferred.
5.	Bandwidth efficiency	10 – 20 MHz/km	1 GHz/km
6.	Attenuation of light	Less typically 0.34 dB/km at 1.3 µm.	More 0.6 to 1 dB/km at 1.3 µm.
7.	Typical light source	LED.	LED, Lasers.

8.	Applications	Subscriber	local

Optic Fiber Configurations

- Depending on the refractive index profile of fiber and modes of fiber there exist three types of optical fiber configurations. These optic-fiber configurations are -

  i) Single mode step index fiber.
  ii) Multimode step index fiber.
  iii) Multimode graded index fiber.

Single mode Step index Fiber

- In single mode step index fiber has a central core that is sufficiently small so that there is essentially only one path for light ray through the cable. The light ray is propagated in the fiber through reflection. Typical core sizes are 2 to 15 μm. Single mode fiber is also known as fundamental or monomode fiber.

Fig. 1.6.16 shows single mode fiber.

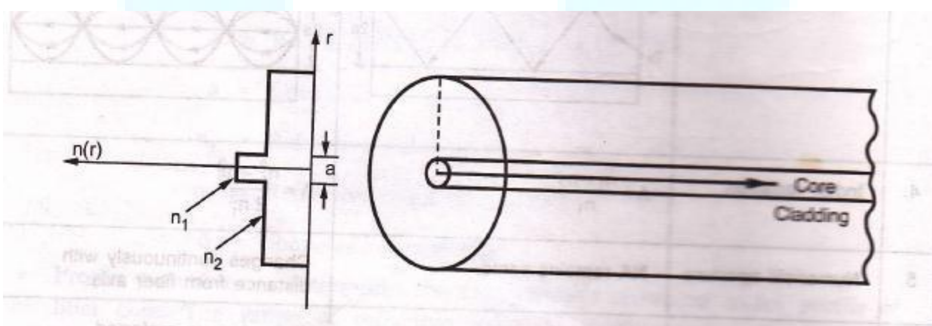

Fig. 1.6.16 The refractive index profile and ray transmission in single mode step index fiber

- Single mode fiber will permit only one mode to propagate and does not suffer from mode delay differences. These are primarily developed for the 1300 nm window but they can be also be used effectively with time division multiplex (TDM) and wavelength division multiplex (WDM) systems operating in 1550 nm wavelength region.

- The core fiber of a single mode fiber is very narrow compared to the wavelength of light being used. Therefore, only a single path exists through the cable core through which light can travel. Usually, 20 percent of the light in a single mode cable actually

travels down the cladding and the effective diameter of the cable is a blend of single mode core and degree to which the cladding carries light. This is referred to as the 'mode field diameter', which is larger than physical diameter of the core depending on the refractive indices of the core and cladding.

- The disadvantage of this type of cable is that because of extremely small size interconnection of cables and interfacing with source is difficult. Another disadvantage of single mode fibers is that as the refractive index of glass decreases with optical wavelength, the light velocity will also be wavelength dependent. Thus the light from an optical transmitter will have definite spectral width.

Multimode step Index Fiber

- **Multimode step index fiber** is more widely used type. It is easy to manufacture. Its core diameter is 50 to 1000 μm i.e. large aperture and allows more light to enter the cable. The light rays are propagated down the core in zig-zag manner. There are many many paths that a light ray may follow during the propagation.
- The light ray is propagated using the principle of total internal reflection (TIR). Since the core index of refraction is higher than the cladding index of refraction, the light enters at less than critical angle is guided along the fiber.

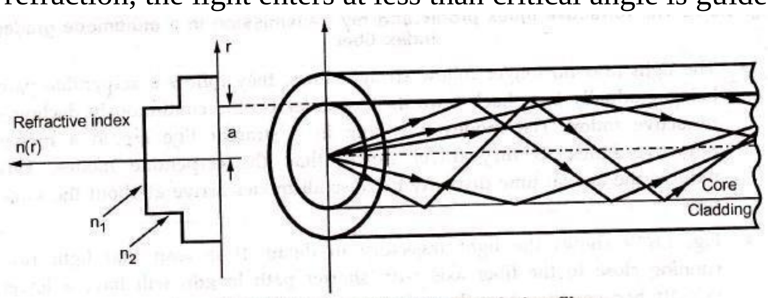

Fig. 1.6.17 TIR in multimode step index fiber

- Light rays passing through the fiber are continuously reflected off the glass cladding towards the centre of the core at different angles and lengths, limiting overall bandwidth.

- The disadvantage of multimode step index fibers is that the different optical lengths caused by various angles at which light is propagated relative to the core, causes the transmission bandwidth to be fairly small. Because of these limitations, multimode step index fiber is typically only used in applications requiring distances of less than 1 km.