UNIT – II WAVES AND OPTICS

TOPIC – VI PRINCIPLE AND PROPAGATION, ACCEPTANCE ANGLE AND NUMERICAL APERTURE

5.14 INTRODUCTION TO FIBRE OPTICS

The development of lasers and optical fiber has brought about a revolution in the field of communication systems. Experiments on the propagation of information – carrying light waves through an open atmosphere were conducted. The atmospheric conditions like rain, fog etc affected the efficiency of communication through light waves. To have efficient communication systems, the information carried by light waves should need a guiding medium through which it can be transmitted safely. This guiding mechanism is optical fiber. The communication through optical fiber is known as light wave communication or optical communication. A light beam acting as a carrier wave is capable of carrying more information than that of radio waves and microwaves due to its larger bandwidth. Currently in most part of the world, fiber optics is used to transmit voice, video and digital data signals using light waves from one place to other place.

5.15 OPTICAL FIBER

It is made up of transparent dielectrics (SiO_2), (glass or dielectrics).

An optical fibre of a central core glass (50μm dia) surrounded by a cladding (125-200μm) which is of slightly lower refractive index than core as as shown in figure 5.19.

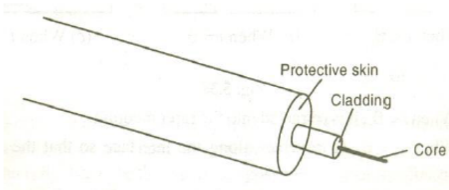


Fig.5.19

The cladding is enclosed by strength members and polyurethane jacket, which act as protective skin for core and cladding as shown in figure 5.19. The protective layer is used so has to make the optical cable to withstand for hard pulling, bending, sketching, rolling etc.. the layer also traps the escaping light from the core.

Features of Optical fibers

(i) It is light in weight

(ii) It is smaller in size

(iii) It is flexible

(iv) It is non – conductive, non – radiative and non – inductive

(v) It has high bandwidth and low loss

(vi) There is no cross talk / internal noise

(vii) It can withstand to any range of temperature and moisture condition.

(viii) No voltage problem occurs

5.16 PRINCIPLE AND PROPAGATION OF LIGHT IN OPTICAL FIBERS

For optical fibers, the process of propagation of light (optical signal) is simple, because once the light enters the fiber, the rays do not encounter any new surfaces, but repeatedly they hit the sane surface. The reason of confining the light beam inside the fibers is the total internal reflection. Even for a bent fiber, the light guidance takes place by multiple total internal reflections all over the length of the fiber as shown in figure 5.20.

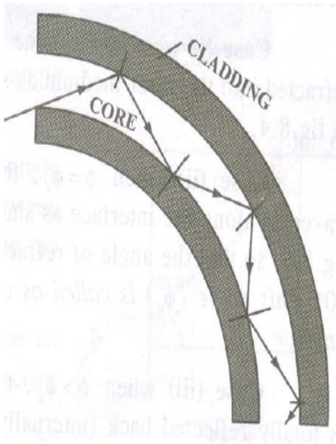


Fig.5.20

Principle

The principle of optical fiber communication is Total Internal Reflection.

Total Internal Reflection

The phenomenon of Total Internal Reflection takes place when it is satisfies the following two conditions.

Condition 1:

Light should travel from denser medium to rarer medium i.e $n_1 > n_2$

Where n_1 = refractive index of core

n_2 = refractive index of cladding

Condition 2:

The angle of incidence on core should be greater than the critical angle.

i.e. $\phi > \phi_c$

Where,

ϕ - angle of incidence

ϕ_c – critical angle

Propagation Phenomenon

Let the light rays traverses from denser medium to rarer medium.

Case i.

When $\phi < \phi_c$ the ray is refracted into the rarer medium as shown in figure 5.21.

Case ii.

When $\phi = \phi_c$, the ray traverses along the interface as shown in figure. So that the angle of refraction is 90°. This angle is called as critical angle.

Case iii.

When $\phi > \phi_c$ the ray is totally reflected back (internally) into the denser medium itself as shown in figure 5.23. From Snell's law (the maximum angle for Total Internal Reflection ϕ_c).

$$n_1 \sin\phi_c = \mathbf{n_2 \sin 90^\circ}$$

$$\sin\phi_c = \mathbf{n_2/n_1}$$

since sin 90° = 1, we have

$$\phi_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

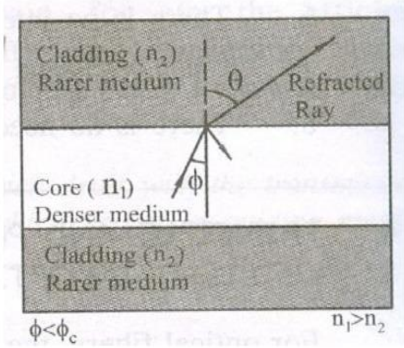


Fig.5.21

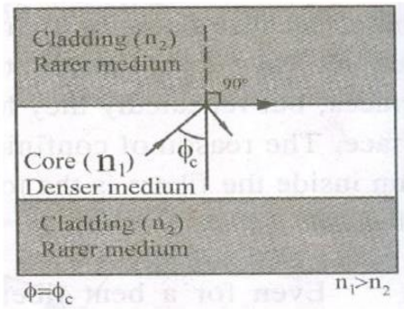


Fig.5.22

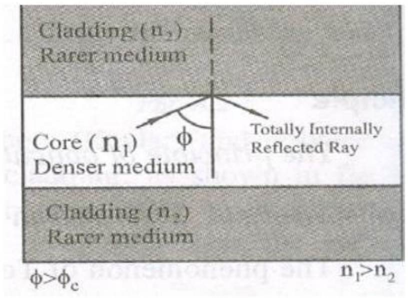
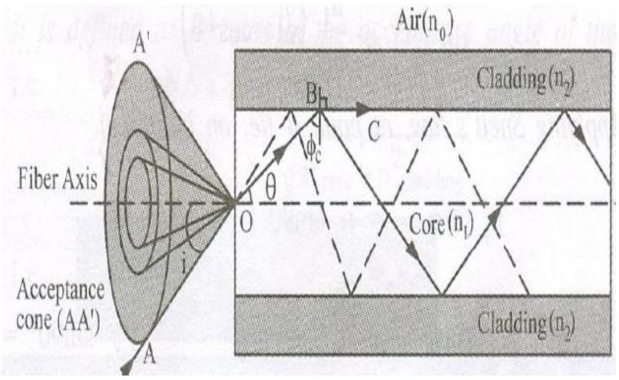


Fig.5.23

5.17 ACCEPTANCE ANGLE AND NUMERICAL APERATURE

Let us consider a cylindrical fiber. it consists of core of refractive index n_1, and cladding of refractive index n_2 and let n_0 be the refractive .

The incident ray travels along AO and enters the core at an angle' i' to the fiber axis.



The ray is refracted along OB at an angle θ in the core as shown in figure 5.24.

It further proceeds to fall at critical angle of incidence (ϕ_c) = 90- θ on the interface between core and cladding. At this angle the ray just moves along BC.

Any ray which enters in to the core at an angle of incidence less than I will have refractive angle less than θ.

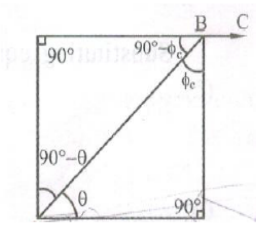


Fig.5.25

Hence, the angle of incidence (ϕ = 90- θ) 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 with in the acceptance angle (cone) will be totally internally reflected. Therefore, the light incident on the core within this maximum external incident angle (i_m) can be coupled into the fiber to propagate. This angle (i_m) is called as wave guide acceptance angle.

Mathematical Relation

i. Applying snell's law, at point entry of ray (AO) we have

$$n_o \sin i = n_1 \sin \theta$$

$$\sin i = \frac{n_1}{n_0} \sin \theta$$

$$\sin i = \frac{n_1}{n_0} \sqrt{1-\cos^2\theta} \qquad \text{------------------ (1)}$$

ii. Applying snell's law, at point B (ie.on surface)

$$n_1 \sin \phi_c = n_2 \sin 90^\circ.$$

$$\sin \phi_c = \frac{n_2}{n_1} \qquad (\sin 90^\circ = 1)$$

$$\sin (90- \theta) = \frac{n_2}{n_1}$$

$$\cos \theta = \frac{n_2}{n_1} \qquad \text{-----------------(2)}$$

substituting equation (2) in equation (1) we get

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

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

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

If the refractive index of air, $n_0 = 1$, then the maximum value of sin i is given as

$$\text{Sin } i_{max} = \sqrt{n_1^2 - n_2^2} \qquad \text{-------------------(3)}$$

Where, n_1 and n_2 are refractive indices of core and cladding respectively.

Acceptance angle

Thus the maximum angle at or below which the light can suffer Total Internal Reflection is called acceptance angle. The cone is referred as acceptance cone.

Numerical Aperture [NA]

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

$$NA = \sin i_m$$

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

$$NA = \sin i_m = \sqrt{n_1^2 - n_2^2} \qquad \text{----------------(4)}$$

Fractional index change (Δ)

It is the ratio of refractive index difference in core and cladding to the refractive index of core.

$$\Delta = \frac{n_1 - n_2}{n_1} \qquad \text{----------------(5)}$$

Relation between NA and Δ

$$n_1\Delta = n_1 - n_2 \qquad \text{----------------(6)}$$

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

(Or) $\quad NA = \sqrt{(n_1 + n_2)(n_1 - n_2)}$ --------------(7)

Substituting equation (6) in equation (7) we have

or $\quad NA = \sqrt{(n_1 + n_2)(n_1\Delta)}$

if $n_1 \approx n_2$, then $NA = \sqrt{2n_1^2\Delta}$

$$NA = n_1\sqrt{2\Delta}$$