SNS COLLEGE OF ENGINEERING

Kurumbapalayam (Po), Coimbatore – 641 107

AN AUTONOMOUS INSTITUTION

Approved by AICTE, New Delhi & Affiliated to Anna University, Chennai.

UNIT – II LASER AND FIBER OPTICS

TOPIC – VI: Principle and propagation of light in optical fibres – Numerical aperture and Acceptance angle

Introduction

The development of lasers and optical fiber has brought about a revolution in communication systems. Experiments on the propagation of information - carrying light waves through open atmosphere have been conducted.

A light beam, acting as a carrier wave, is capable of carrying more information than that of radiowaves and microwaves due to its larger bandwidth.

Often atmospheric conditions like rain, fog, etc., affect the efficiency of communication through light waves. To have an efficient communication system, the information carried by light waves require a guiding medium through which it can be transmitted safely.

This guiding medium is optical fiber. The communication through optical fiber is also known as light wave communication. The study of light propagation through fibers is known as fiber optics.

Currently, in most part of the world, fiber optics is used to transmit voice, video and digital data signals through light waves from one place to other place.

A bundle of optical fibers consists of thousands of individual fiber wires as thin as human hair, measuring 0.004 mm in diameter. (Fig .1)

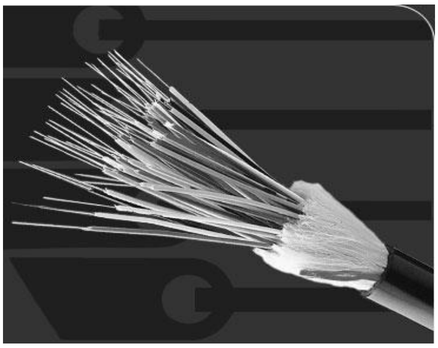


Fig .1 Bundle of Optical fibers

Principles of Optical Fiber

Optical fiber is a wave guide, made of transparent dielectric (glass or plastic) in cylindrical form through which light is transmitted by total internal reflection**.** It guides light waves to travel over long distance without much loss of energy.

Optical fiber consists of an inner cylinder made of glass or plastic called core of very high refractive index n_1. The core is surrounded by a cylindrical shell of glass or plastic called cladding of lower refractive index n_2. The cladding is covered by a jacket that protects the fiber from moisture and abrasion. (Fig.2)

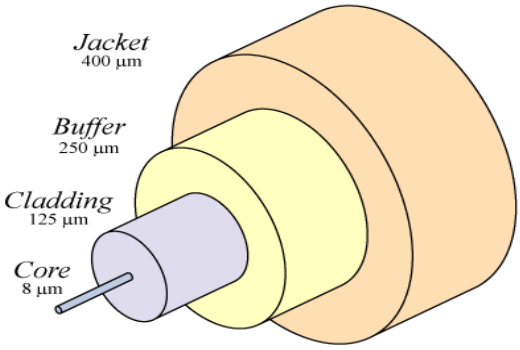


Fig .2 Structure of Optical fiber

A light ray AO traveling in a medium of refractive index n_1 is incident on another medium of lower refractive index n_2 at the boundary XX'. A part of light ray is reflected back into the first medium and the remaining part is refracted through the second medium (fig.3).

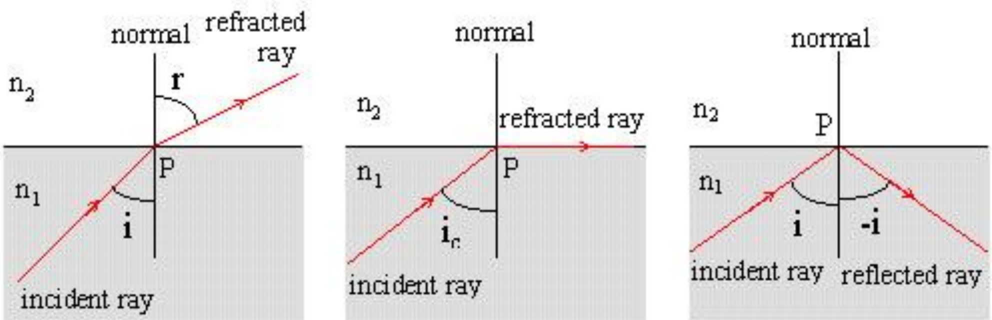


Fig .3 Ray diagram

The reflection or refraction at the interface is a result of difference in the speed of light in two materials having different refractive indices.

Case 1

The incident ray AO makes an angle θ_1 with the normal in the medium of refractive index n_1. This ray is refracted into the medium of refractive index n_2 and bends away from the normal because the refractive index of first medium n1 is greater than the refractive index of the second medium n_2.

i.e., $n_1 > n_2$

The angle made by the refracted ray with normal is θ_2.

Then $\theta_2 > \theta_1$

Case 2

When the angle of incidence (θ_1) is increased for a certain value of critical angle (θ_c), θ_2 is 90^0, i.e., the refracted ray just emerges along the boundary of separation OB' while the incident ray is along BO.

Case 3

When the angle of incidence (θ_1) is greater than the critical angle of incidence (θ_c), the incident ray 'OC' is reflected back into the originating medium by total internal reflection (fig).

For the refraction of light, Snell derived the relation between the angle of incidence (θ_1) and angle of refraction (θ_2) as

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

For total internal reflection,

$$\theta_1 = \theta_c and \theta_2 = 90^0$$

$$n_1 \sin \theta_c = n_2 \sin 90^0$$

$$\sin \theta_c = \frac{n_2}{n_1} \qquad \because \sin 90^0 = 1$$

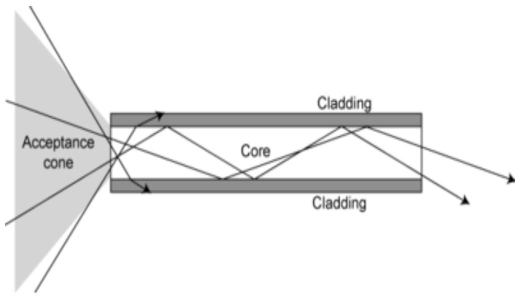
$$\therefore \quad n_1 \sin \theta_c = n_2$$

$$\sin \theta_c = \frac{n_2}{n_1} \qquad \therefore \quad \boxed{\theta_c = \sin^{-1}\left(\frac{n}{n_1}\right)}$$

Thus, total internal reflection in the walls of optic fiber can occur in the following two conditions:

- The glass around the centre of fiber (core) should have higher refractive index (n_1) than that of the material (cladding) surrounding the fiber (n_2).
- The light should be incident at an angle (between the path of the ray and normal to the fiber wall) greater than the critical angle (θ_c).
- **Acceptance Angle**
- **The maximum angle (θ_0) at which a ray of light can enter through one end of the fiber and still be totally internally reflected is called acceptance angle of the fiber. It is given by the expression.**

- $$\therefore \sin\theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$
-
- $$\therefore \text{Acceptance angle,} \quad \theta_0 = \sin^{-1}\frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$
-
- If the medium surrounding the fiber is air $n_0 = 1$
- $$\therefore \text{Acceptance angle,} \quad \theta_0 = \sin^{-1}\sqrt{n_1^2 - n_2^2}$$
- Thus, the light that travels within a cone defined by the acceptance angle is confined and guided. This is the fundamental property of light propagation in a fiber. The cone is referred as acceptance cone.(Fig .6)



- **Fig .6 Acceptance cone**
- **Numerical Aperture**
- **The sine of the acceptance angle of the fiber is known as numerical aperture (NA). It denotes the light gathering capability of the optical fiber.**
- $$NA = \sin\theta_0$$
- $$NA = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$
- If the medium surrounding the fiber is air , then
-
- $$\therefore \text{Acceptance angle,} \quad NA = \sqrt{n_1^2 - n_2^2} \qquad \because n_0 = 1$$
- **Condition for propagation of light**
- Let θ_I be the angle of incidence of an incident ray. Then, the light ray will be able to propagate
- if $\theta_i < \theta_0$

$$or \sin\theta_i < \sin\theta_0$$

$$or \sin\theta_i < \sqrt{n_1^2 - n_2^2}$$

$$i.e., \sin\theta_i < NA$$

- **This is the condition for propagation of light within the fiber.**