UNIT- VI.

- Optical Communication -

→ Introduction to optical fiber ← 09

Optical fiber is the name given to a fiber type wire of diameter of the order of human hair. The light signal can travell along these fibers without any effective loss. The fiber is of diameter about 125 um. Opt

i.e. " An optical fibre is a hair - thin flexible transparent medium of cylindrical shape usually made of glass through which light can be propagated."

The optical fibre has three principal sections such as (i) the core (ii) the cladding and (iii) the jacket.

The core is the innermost section of the fibre (fig 6.1) and has a remarkable property of conducting an optical beam. It is made of glass or plastic. The core, the actual working structure of the fibre, is covered with another layer of glass with slightly different chemical composition or plastic, called cladding. The cladding has optical properties very different from those of the core. The optical fibre may have a abrupt boundary between the core and cladding or there may be a gradual change in the material between the two. The outermost section of the fibre is called, the jacket and is made of plastic or special kind of polymer and other material. The opaque protective jacket protects the core from abrasion, interaction with enviroment, moisture, absorption, crushing and other

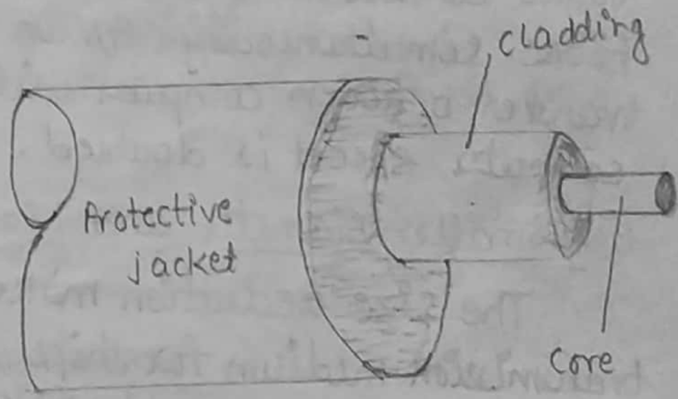

Fig-6.1- Schematic of optical fiber

vegaries of the terrestrial atmosphere and thus enhances its tensile strength. In fact the humidity of a normal atmosphere causes micro-cracks on the fibre surface to grow, which eventually degrades inherent high tensile strength of the fibre. The core acts like a continuous layer of two parallel mirrors

Advantages

There are many advantages of fiber optics. The primary ~~Its~~ advantages are following.

(i) Extremely Large Bandwidth – The bandwidth available with fibre optic is enormous (more than 100 GHz). With such a large bandwidth, it is possible to transmit thousands of voice conversations or dozens of video signals over the same fibre simultaneously. As an example, memory to memory transfer between computer will now be possible even if the computer speed is doubled.

(ii) Smaller Diameter and Lighter weight –

The size reduction makes fiber optical cables the ideal transmission medium for ships, aircrafts and high rise buildings were bulky copper cables take up too much space. Together with the reduction is size goes an enormous reduction in weight. It is an important advantage in aircraft, missiles and satellites.

(iii) No Crosstalk Between Parallel Fibers –

In conventional communication circuits, signals often stray from one circuit to another, resulting in other cells being heard in the background. This crosstalk is negligible with fiber optics even if numerous fibers are cabled together

(iv) Longer Life span →

A Longer life span of 20 to 30 years is predicted for the fiber optics cables as compared to 12 to 15 years for the conventi-onal cables. The main reason for this is that glass does not corrode as metal does

(v) No externally Radiated Signal –

As fiber optic cables do not radiate signals, the fiber optic transmission doesn't interfere with other services. In fiber optics, signal confinement is excellent.

(vi) Immunity to Inductive Interference.

(vii) Potential of Delivering Signals at a lower cost.

(viii) Greater Saffty.

(ix) Easy of Expansion of system capability.

(x) High tolerance to temperature extremes, liquids and corrosive gases.

– Optical Propagation Theory –

Ray Optics – {or Ray Transmission}.

In an optical fiber, light rays are guided by total internal reflection at the interface between fiber core and cladding as shown in fig. 6.2. However, only those rays are guided which fulfil the condition of total internal reflection determined by snell's law discussed below. In this case, ray follow a zig-zag path along the fiber core with ongoing internal reflections. As these rays intersect the axis (centre line) of the fiber after each reflection, they are called meridional rays. As shown in fig 6.2. Input ray is refracted when entering the fiber core because RI no of the

surrounding medium is different from that of fiber core (n_1).
If input angle is too large, ray in fiber counenters the cladding and is no longer guided.

In contrast to meridional rays, skew rays propagate by forming a spiral (helical path) around the fiber axis as in fig 6.3. Skew rays are three dimensional rays, whereas meridiorn rays propagate in a two dimensional plane. It may be seen from fig 6.3 that the helical path traced through the fiber gives a change in direction of 2γ at each reflection where γ is the angle between the projection of the ray in two dimensions and the radius of fiber core at the point reflection. Unlike meridional rays, the point of emergence of skew rays from the fiber in air vapour depend upon the number of reflections these rays undergo rather than the input conditions to fiber.

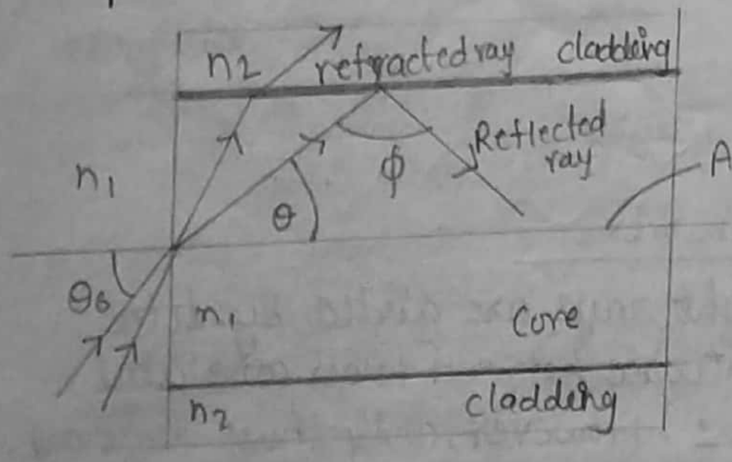

fig- 6.2 - meridional ray propagation in a step index fiber

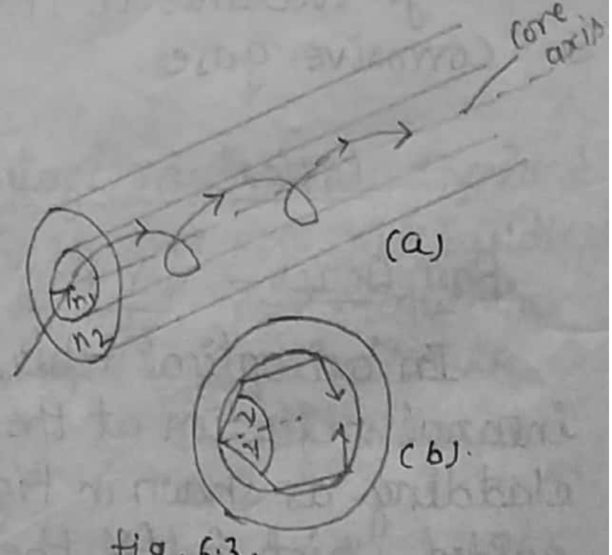

fig. 6.3.
(a) skew ray path along the fiber length and
(b) Cross-sectional view of the fiber.

Numerical Aperture (NA) → 09,11

Let us now consider the propagation of meridional.

rays in a step index fiber as in fig 6.2. from Snell's law, the minimum angle ϕ_{min} that support total internal reflection for the meridional ray is given by.

$$\sin(\phi_{min}) = \frac{n_2}{n_1} \quad \text{---(i)}$$

The rays for which the incident angle at the core-cladding interface is less than ϕ_{min} will be refracted out to the cladding and be lost there. The maximum incident angle θ_0 max for rays to propagate in the core through the mechanism of total reflection from equn(i) is given by.

$$n_0 \sin(\theta_{0,max}) = n_1 \sin(\theta_0) = \sqrt{n_1^2 - n_2^2} \quad \text{----(ii)}$$

where $\theta_0 (= \frac{\pi}{2} - \phi_c)$ is the critical angle and n_0 the RI of outside medium which is generally air (for air $n_0 = 1$). The above equn also defines the numerical aperture (NA) of a SI fiber for meridional rays,

$$\boxed{NA = n_0 \sin(\theta_{0,max}) = \sqrt{n_1^2 - n_2^2} = n_1\sqrt{2\Delta}} \quad \text{--- (3)}$$

The NA is an important parameter for an optical fiber as it discribes the light acceptance or gathering capability of a fiber. It is a demensionless quanlity which is normally less than unity and range from 0.14 to 0.50. Typically, NA of telecommanication fibers is 0.1 to 0.2 which emplies an acceptance angle of 5.7° to 11.5°. However, for non-telecommunication applications like in endoscope, NA could be much higher than 0.5 (i.e. $\theta_0 > 30°$). For skew rays, Eq. (3) gets modified as.

$$NA = n_0 \sin(\theta_{s,max}) \cos(\gamma) = \sqrt{n_1^2 - n_2^2} = n_1\sqrt{2\Delta} \quad \text{——— (4)}$$

where θ_s max. is the maximum input angle within which the incident rays will be totally internally reflected. It is clear from the above equation that the skew rays are accepted at larger axial angles in a fiber of given NA than the meridional rays depending upon the value of $\cos(\gamma)$. In fact, for the meridional rays, $\cos(\gamma)$

is equal to unity and $\theta_{s,max}$ becomes equal to $\theta_{0,max}$. Through $\theta_{0,max}$ is the maximum critical half angle for the acceptance of meridional rays, it defines the minimum input angle for the skew rays. For most communication design purposes, the expression for NA given in equn (3) for meridional rays is adequate.

Types of optical fibers

The fibers are classified into two main types-

(i) Monomode fiber (ii) Multimode fiber.

Monomode fiber → The monomode fibers has a very narrow core of the diameter about 5 µm or less. So the cladding is relatively big.

multimode fiber – The multimode fiber has a core relatively large diameter such as 50 µm. It is of two types-

(a) Step Index multimode fiber

(b) Graded Index multimode fiber.

Step Index multimode fiber – 07, 09

It has a core of constant refractive index n from its centre to the core cladding boundary than the refractive index changes to a lower value of n_2 which is constant from core-cladding boundary upto the outer surface of the cladding.

Graded Index multimode fiber – 07, 09

In this type of optical fiber the refractive index decreases continuously from the centre through out the outer surface of the cable so we can't distinct core and cladding at a particular position.

Comparison of single mode index & Multimode Index fibres 2012

SMF	MMF
1. In a single mode index fibre, the diameter of the core is very small & is of the same order as the wavelength of light to be propagated. It is in the range 5 µm - 10 µm. The cladding diameter is about 125 µm.	1. In a multimode fibre, the diameter of the core is large. It is in the range 30 µm - 100 µm. The cladding diameter is in the range 125 µm - 500 µm.
2 - In SMF only a single mode is propagated.	2 - In MMF, a large number of modes can be propagated.
3 - SMF is more expensive, but more efficient.	3. MMF is less expensive
4. Modal dispersion in SMF is almost nill	4 Modal dispersion in MMF is the dominant source of dispersion.
5. material dispersion in sm fibre is low	5. material dispersion in MMF is large.
6. NA of SMF is small	NA of MMF is large.

Comparision between Step Index & Graded Index fibres

SIF	GRIF
1. In a step index fibre, the refractive index of the core has a constant value	1. In graded Index fibre, the refractive index is the core decreases continuously in a nearly parabolic manner from a maximum value at the centre of the core to a constant value at core-cladding interface.
2- For a SIF, a variation of refractive index is mathematically expressed as $\mu(r) = \mu_1 \quad 0 < r < a$ (core) $= \mu_2 \quad r > a$ (Cladding) where $\mu_1 > \mu_2$	2- Parabolic refractive index variation in GRIF is mathematically expressed as $\mu^2(r) = \mu_1^2\left[1 - \left(\frac{r}{a}\right)^2\right] \quad 0 < r < a$ [core] $= \mu_2^2 \quad r > a$ [cladding]

3- In SIF the propagating light rays reflect abruptly from the core cladding boundary.	3. In GRIF propagating light rays bend smoothly as they approac the cladding.
4- SIF has higher attenuation	4. GRIF has lower attenuation
5. Pulse dispersion in multimode step index fibre is large	5. Pulse dispersion in a GRIF is small.