General optical fiber communication System:-

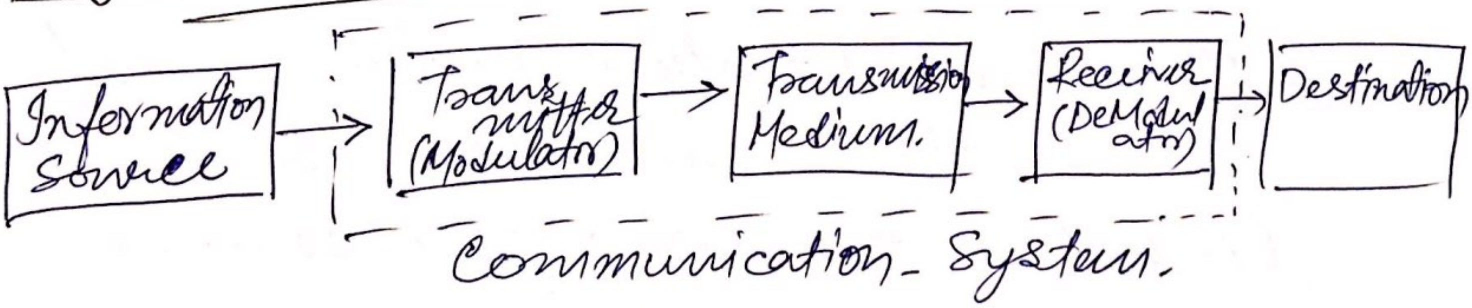
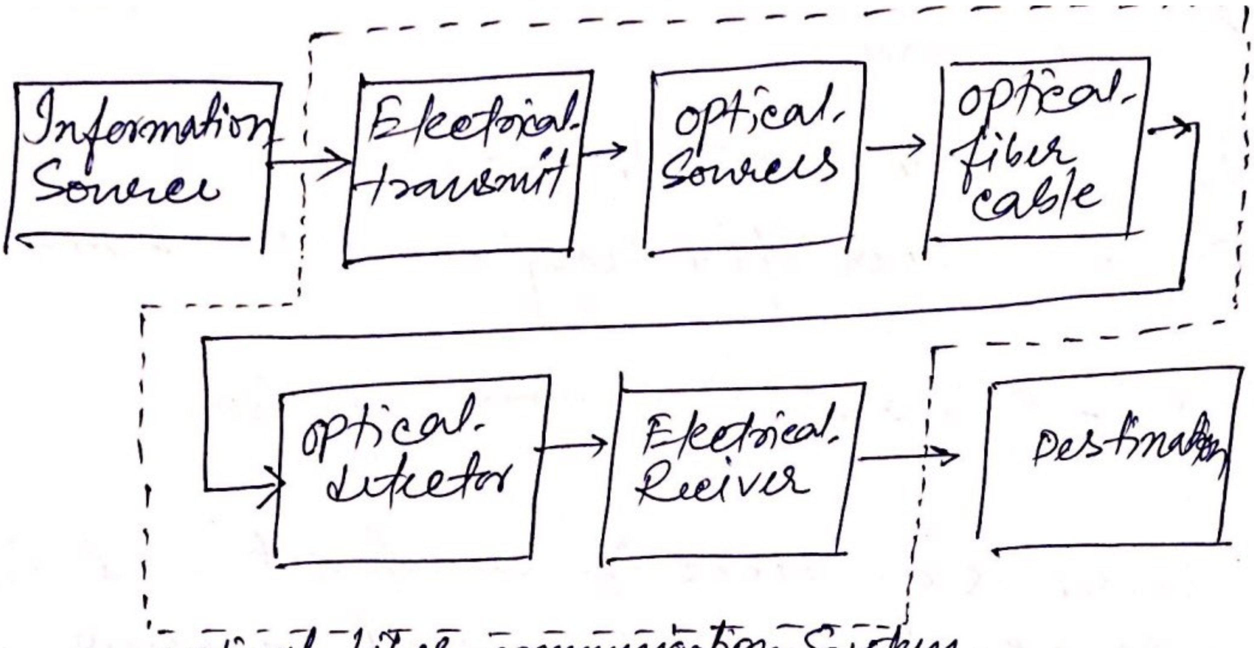


Fig-@



optical fiber communication System.

Fig. (b).

(1). A schematic block of a general communication system is shown in figure (a), the function of which is to convey the signal from the information source over the transmission medium to the destination.

(2) The communication system therefore consists of a transmitter or modulator linked to the information source, the transmission medium and a receiver or de-modulator linked to the ~~information~~ destination point.

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③. In electrical communications the information source provides an electrical signal normally derived from a message signal which is not electrical (e.g.- Sound), to a transmitter comprising electrical and electronic components which converts the signal into a suitable form for propagation over the transmission medium. This is often achieved by modulating a carrier.

④ The transmission medium can consist of a pair of wires, a coaxial cable or a radio link through free space. down which the signal is transmitted to the receiver, where it is transformed into the original electrical information by demodulating the received signal.

⑤. It must be noted that in any transmission medium the signal is attenuated or suffers losses due to contamination by noises as well as distortion imposed by the medium itself.

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⑥. Therefore in any communication system there is a maximum distance between the transmitter and receiver beyond which the system fails to give clear communication.

⑦. To avoid this problem in long distance communications repeaters or amplifiers are placed at necessary intervals, both to remove signal distortion and to increase signal level.

⑧. For optical fiber communication as shown in figure ⓑ, the information source provides an electrical signal to a transmitter ~~com~~ consisting an electrical stage which drives an optical source to give modulation of the lightwave carrier.

⑨ The optical source which provides the electrical to optical conversion may be either a semiconductor laser or a light emitting diode (LED).

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⑩ The transmission medium consists of an optical fiber cable and the receiver consist of an optical detector which derives a further electrical stage and hence provides demodulation of the optical carrier.

⑪. Photo diodes and in some cases phototransistors and photoconductors are used for detection of optical signal and optical to electrical conversion.

⑫. The optical carrier may be modulated using either an analog or digital signal. Though analog modulation is simple it is less efficient. Therefore analog optical fiber communication are generally limited to short distance and low bandwidth.

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⑪

(13) The above figure shows a schematic block diagram of digital optical fiber link.

(14) The i/p digital signal from the information source is ~~sent~~ encoded for optical transmission.

(15) The LASER drive ckt directly modulates the encoded digital signal. Hence a digital optical signal is ~~passed through~~ the optical fiber cable.

(16) The avalanche photodiode (APD) detector is followed by a front end amplifier and equalizer or filter to provide gain and noise reduction.

(17) Finally the signal is decoded to give original digital information.

— (6) —

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Advantages of optical fiber communication

(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 optical fiber cables are much higher.

(2) Low transmission loss :-

Fiber optic cables offers very less signal attenuation over long distance, generally it is less than 0.85 dB/km. This enables longer distance between the repeaters.

(3) Small size and weight :-

Optical fibers ~~are~~ have very small diameters which are often not greater than human hair.

(4) Electrical isolation :-

As the fibers are fabricated from glass or plastic polymer, they work as electrical insulators and therefore they does not exhibit interface problems.

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⑤. Immunity to interface and crosstalk:-

Since the cables are nonconductors of electricity, they donot produce magnetic fields. Thus fiber optic cables are immune to crosstalk between cables caused by magnetic induction.

⑥ Signal security:- The light from optical fibers does not radiate significantly and therefore provide a high degree of signal security.

⑦ Long distance transmission:-

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

⑧ Low cost:-

The glass which generally provides the optical fiber transmission medium is made from sand - not a inadequate resource.

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9. Flexibility:- Due to its compact structure these cables are very flexible and ~~strong~~. (tough)

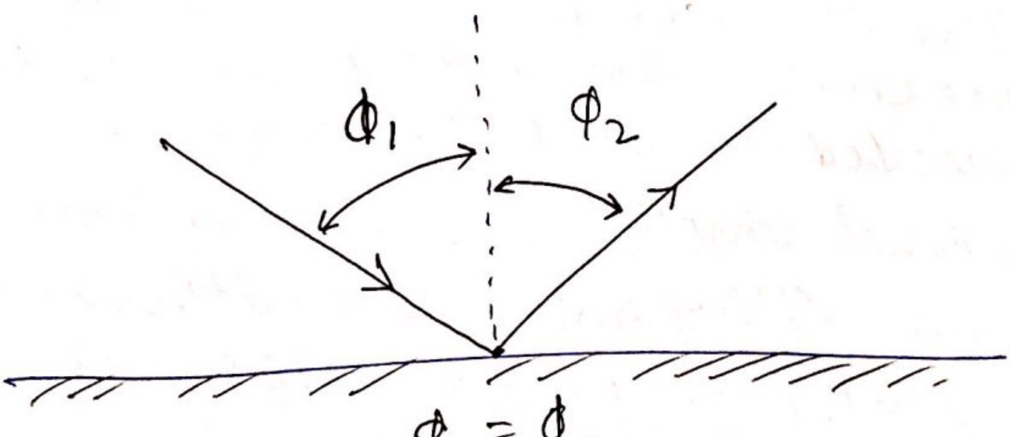
10. Ease of maintenance:-
As the fiber optic cables provide low-loss, there is less requirements of intermediate repeaters or line amplifiers to boost the transmitted signal strength.

Disadvantages:-

1. High initial cost
2. Maintenance and Repairing cost
3. The distance b/w the transmitter and receiver should keep short or repeaters are needed to boost the signal.
4. Light emitting sources are limited to low power. Although high power emitters are available to improve power supply, it would add extra cost.
5. Optical cables are fragile and more vulnerable to damage compare to copper wires.

— 4 —

Reflection :- The law of reflection states that when a light ray is incident upon a reflective surface at some incident angle (ϕ_1) from imaginary perpendicular at the point of incident, the ray will be reflected from the surface at some angle ϕ_2 from the normal, which is equal to the angle of incident.



$\phi_1 = \phi_2$

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Refraction:- Refraction occurs when light ray passes from one medium to another medium, i.e. the light ray changes its direction at interface.

→ When wave passes through less dense medium to more dense medium, the wave is refracted towards the normal.

→ When wave passes through more dense medium to less dense medium, the wave is refracted away from the normal.

(2)

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Refractive Index:-

The amount of refraction or bending that occurs at the interface of ~~the~~ two ~~materials~~ medium of different densities is usually expressed as refractive index and it's denoted by 'n'.

⟹ Based on the material density the refractive index is expressed as the ratio of the velocity of light in freespace to the velocity of light in that material.

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The refractive index of a medium is defined as the ratio of the velocity of light in a vacuum to the velocity of light in the medium.

$$n = \frac{\text{speed of light vacuum}}{\text{" \quad " \quad " \quad medium}} = \frac{c}{v}$$

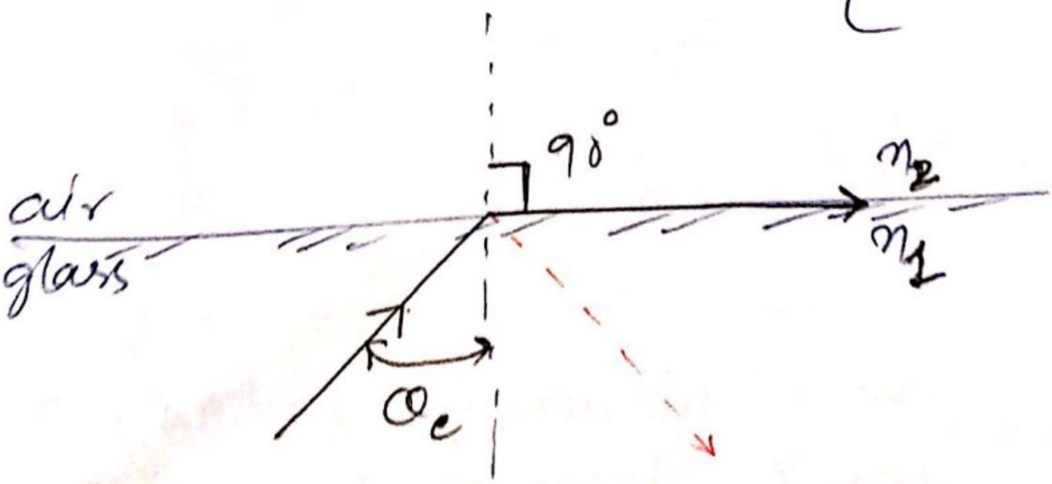
* refractive index for vacuum and air is 1, for water is 1.3 and for glass is 1.5.

— (2) —

Critical angle :-

It is the angle of incident when light passes from high dense medium to low dense medium and the angle of refraction is 90°.

$$\left\{ \sin\theta_c = \frac{n_2}{n_1} \right\}$$



②

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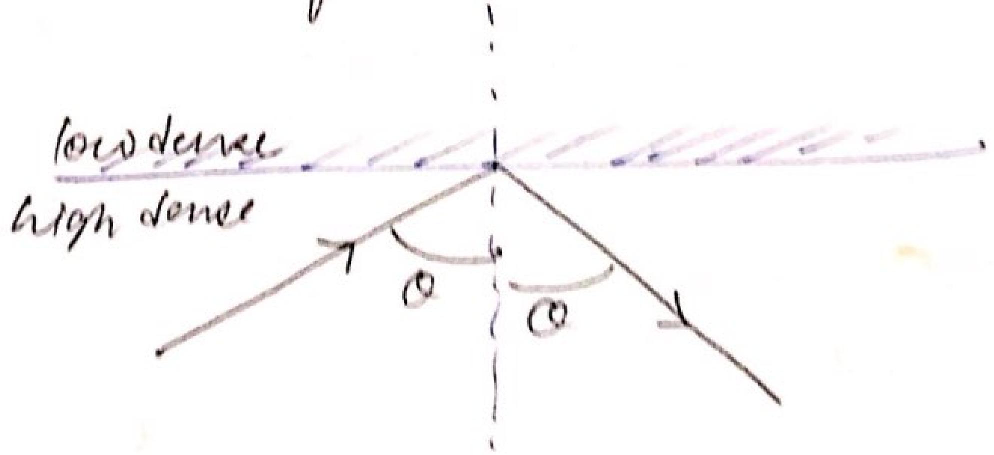
Total internal reflection:-

When light travels from high dense medium to low dense medium and the angle of incident is greater than the critical ~~con~~ angle, the light is reflected back into the originating medium. This phenomenon is called total internal reflection.



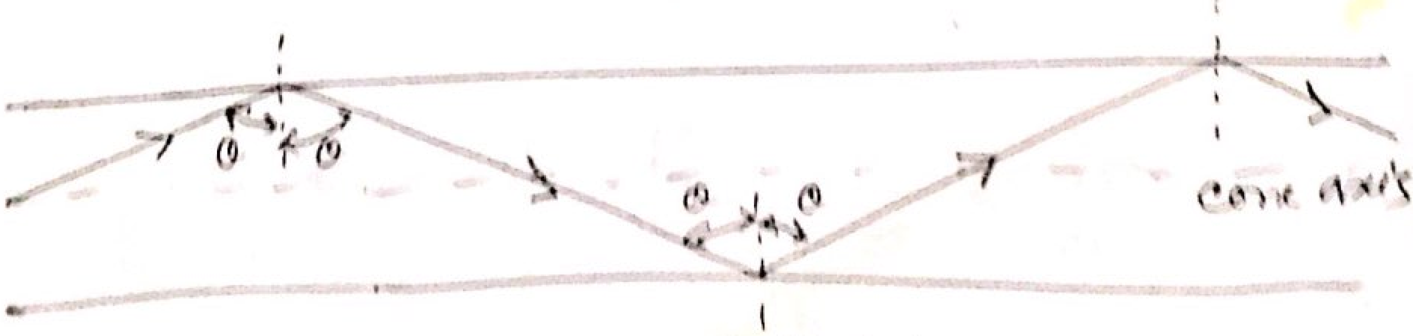


Fig: Transmission of light ray in a perfect optical fiber.

(2)

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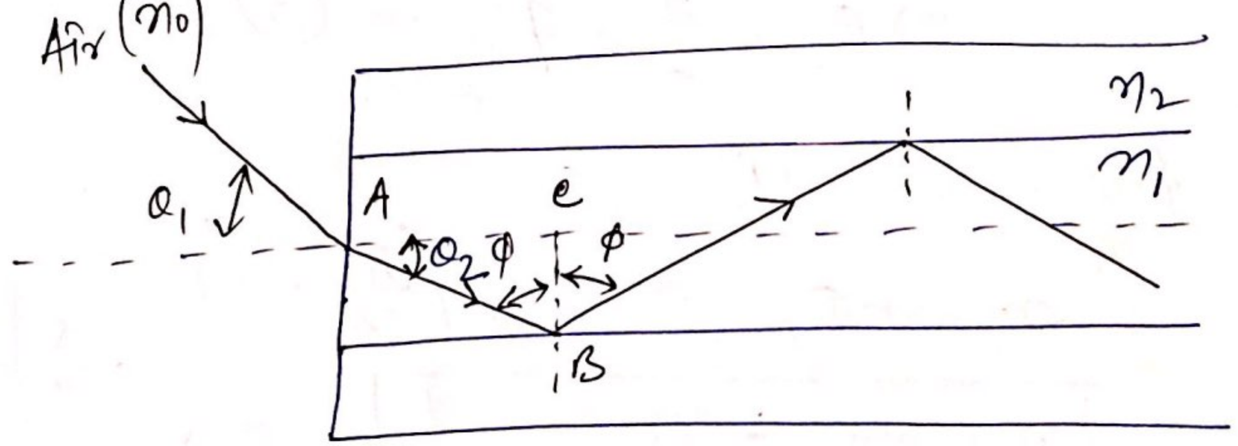
Numerical Aperture:

→ The numerical aperture (NA) of an optical system, is a dimensionless number, that characterizes the range of angles over which the system can accept or emit light.

→ The larger the NA, the greater will be the acceptance of light.



→ The above figure shows a light ray incident on the fiber core at an angle θ_1 to the fiber axis, which is lesser than the acceptance angle 'θ_a'.

→ The ray enters the fiber from a medium (air) of refractive index (n_0) and core has refractive index 'n_1', which is slightly greater than the cladding (R.I) n_2

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Applying Snell's law at (air core) interface

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_1}{n_0}$$

$$\Rightarrow n_0 \sin\theta_1 = n_1 \sin\theta_2 \quad \text{--- (1)}$$

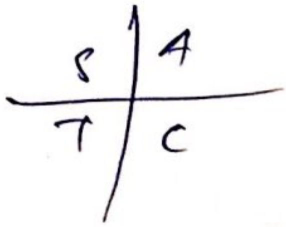
considering the triangle ABC (right-angle)

$$\theta_2 + \phi = \frac{\pi}{2}$$

$$\Rightarrow \theta_2 = \frac{\pi}{2} - \phi \quad \text{--- (2)}$$

from eq^n (1)

$$n_0 \sin\theta_1 = n_1 \sin\left(\frac{\pi}{2} - \phi\right)$$



$$\boxed{n_0 \sin\theta_1 = n_1 \cos\phi} \quad \text{--- (3)}$$

using the relationship -

$$\sin^2\phi + \cos^2\phi = 1$$

$$\Rightarrow \cos^2\phi = 1 - \sin^2\phi$$

$$\Rightarrow \cos\phi = \sqrt{1 - \sin^2\phi}$$

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∴ from eqⁿ ③ =

$$n_0 \sin\theta_1 = n_1\left(\sqrt{1-\sin^2\phi}\right) \quad \text{—} ④$$

* If the limiting case for total internal reflection is consider, ϕ becomes equal to the critical angle for core-cladding interface.

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

$$\Rightarrow \sin\phi = \frac{n_2}{n_1}$$

eqⁿ ④.

$$\Rightarrow n_0 \sin\theta_1 = n_1\sqrt{1-\left(\frac{n_2}{n_1}\right)^2}$$

$$\Rightarrow n_0 \sin\theta_1 = n_1\sqrt{\frac{n_1^2-n_2^2}{n_1^2}}$$

$$\Rightarrow n_0 \sin\theta_1 = \sqrt{n_1^2-n_2^2}$$

also considering $\theta_1 = \theta_a$

$$* \quad n_0 \sin\theta_a = \sqrt{n_1^2-n_2^2} \quad * = NA$$

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NOTE Since NA is generally used with the fiber in air where $n_0 = 1$

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

also $0 \le \phi_1 \le \theta_a$

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

~~$\therefore \sqrt{n_1^2 - n_2^2}$~~

~~$n_1^2 - n_2^2 = (n_1 + n_2)(n_1 - n_2)$~~

~~$= n_1^2 - n_1 n_2 + n_1 n_2 - n_2^2$~~

The NA may also be defined as the relative refractive index difference (Δ) between the core and the cladding.

where $$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

$$\therefore NA = n_1\sqrt{(2\Delta)}$$

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(2017) VTU

Q. A silica optical fiber with core diameter large enough to be considered by ray theory analysis has a core refractive index of 1.50 and cladding refractive index of 1.47.

Determine -

(a) The critical angle at the core cladding interface.

(b) NA for the fiber.

(c) Acceptance angle.

Solution :-

(a) $\sin\theta_c = \left(\frac{\text{cladding}}{\text{core}}\right) = \frac{1.47}{1.50}$

$\Rightarrow \theta_c = 78.5^\circ$

(b) $NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.5)^2 - (1.47)^2}$

$= 0.30$

(c) $\theta_a = \sin^{-1}(NA)$

$= 17.4^\circ$

(3)

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(b) Estimate the maximum core diameter for an optical fiber with refractive index difference of 1.6% and a core refractive index of 1.48 in order that it may be suitable for single mode operation for an.

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wavelength of 0.9μm. Further find out the maximum core diameter for a single mode operation when the refractive index difference is reduced by a factor of 10. Assume V number as 2.405.

⇒ Given, $\Delta = 0.016$

$n_1 = 1.48$

$\lambda = 0.9\,\mu m$

$V = 2.405$

~~$V = \frac{2\pi}{\lambda} a\, NA$~~

~~$\Rightarrow a = \frac{V\lambda}{2\pi NA} =$~~

$V = \frac{2\pi}{\lambda} a n_1 (2\Delta)^{\frac{1}{2}}$ → 0.1789

$a = \frac{V\lambda}{2\pi n_1\, 0.1789}$

$= 1.3 \times 10^{-6}$ m.

(7)

diameter = 2.6×10^{-6} m.

$\Delta = 0.016 \times \frac{1}{10}$ = ~~0.16~~.

$= 0.0016$

$(2\Delta)^{\frac{1}{2}}$

$= 0.0566$

$a = \frac{V\lambda}{2\pi n_1\, 0.0566} = 4.16 \times 10^{-6}$ m.

Diameter = 8.23μm.

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Q. A multimode graded index fiber has a core diameter with a parabolic refractive index is 60μm. The fiber has an NA of 0.2. Estimate the total number of modes in the waveguide at a wavelength of 1μm.

Sol:-

given.

diameter = 60μm.

$a = 30\mu m$.

$NA = 0.2$

$\lambda = 1\mu m$.

$$V = \frac{2\pi}{\lambda} a \cdot NA$$

$$= \frac{2 \times 3.14}{1 \times 10^{-6}} \times 30 \times 10^{-6} \times 0.2$$

$$= 37.68$$

$$\text{No of modes } (M) = \frac{v^2}{4} = \frac{(37.68)^2}{4}$$

$$= 354.95$$

$$\simeq 355$$

(3)

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Modes of Fiber

The mode of a fiber refers to the number of paths for the light rays within the cable.

According to the modes optical fibers can be classified into two types.

① Single Mode fiber.

② Multimode fiber.

* Single mode fiber allows propagation of light ray by only one path. Single mode fibers are good for long distance communication and does not exhibit dispersion caused by multiple modes.

* The term multimode simply refers to the fact that multiple modes are carried simultaneously through the wave guide. They are much larger in diameter compare to single mode and this allows large number of modes.

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Fiber Profiles:-

① A fiber is characterized by its profile and by its core and cladding diameters.

② One way of classifying the fiber cable is according to the index profile at fiber.

③ The index profile is a graphical representation of value of refractive index across the core diameters.

There are two basic types of index profiles

① Step index fiber

② Graded index "

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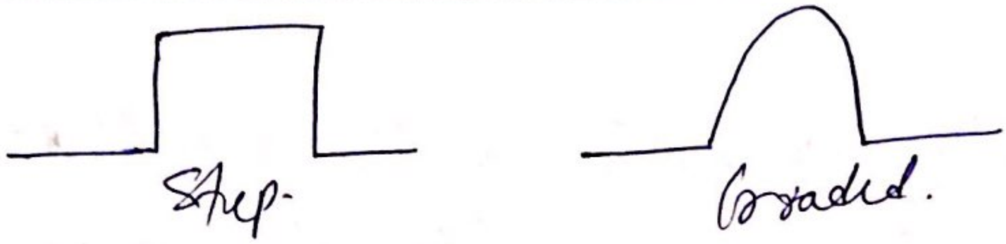

Step Index (SI) fiber:-

① The step index (SI) fiber is a cylindrical wave guide ~~core~~ with central or inner core ~~is surrounded by outer cladding~~ has a uniform refractive index 'n_1' and the core is surrounded by ~~outer~~ outer cladding with uniform refractive index 'n_2'. The cladding R.I. (n_2) is lesser than core R.I. (n_1) $[n_2 < n_1]$

② This is because the refractive index profile for this type of fiber makes a step change at the core - cladding interface, ~~as~~ indicated in the figure.

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

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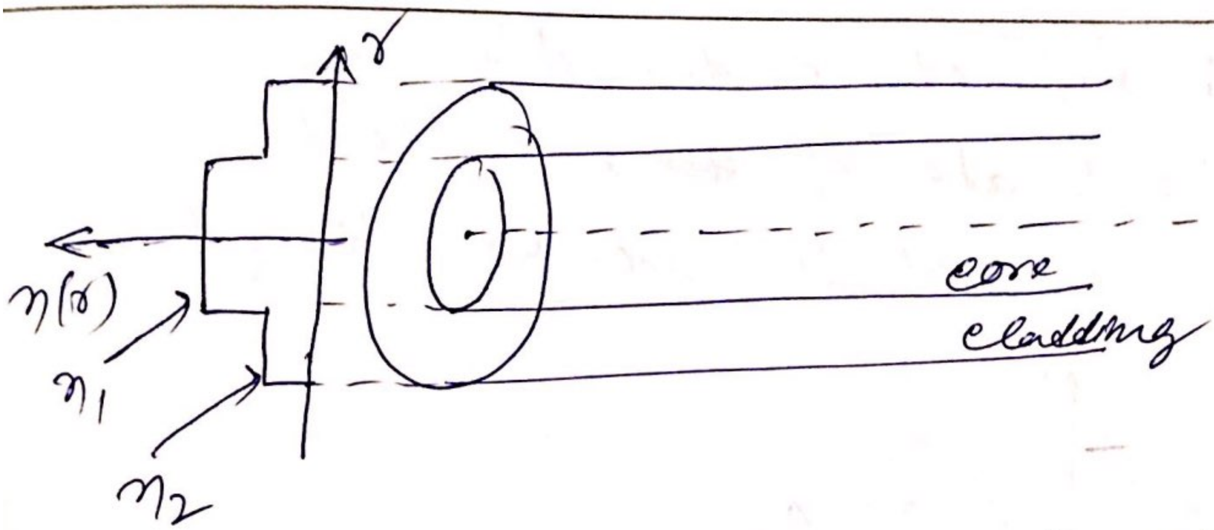

→ core is typically has diameter 50-80 μm. and the cladding has a diameter 125 μm.

Graded Index Fiber:-

The graded index fiber has a core made from many layers of glasses.

① In the graded index fiber, the refractive index is not uniform with in the core, it is highest at the center and decreases smoothly and continuously with distance towards the cladding.

$$n(r) = \begin{cases} n_1\left[1-2\Delta\left(r/a\right)^{\alpha}\right]^{\frac{1}{2}} & r<a \text{ core} \\ n_1\left(1-2\Delta\right)^{\frac{1}{2}} & , r \geq a \text{ cladding.} \end{cases}$$

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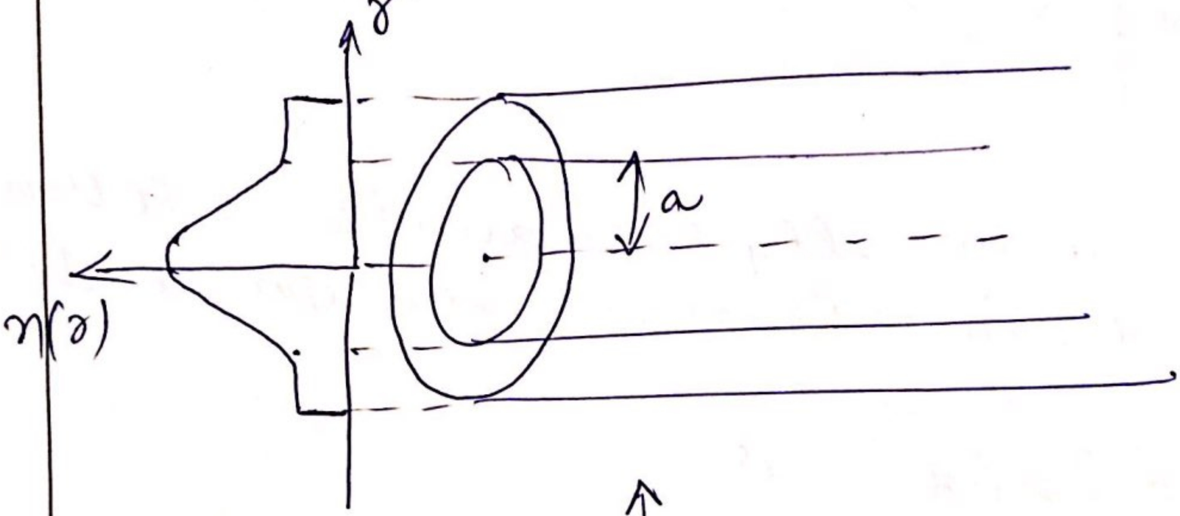
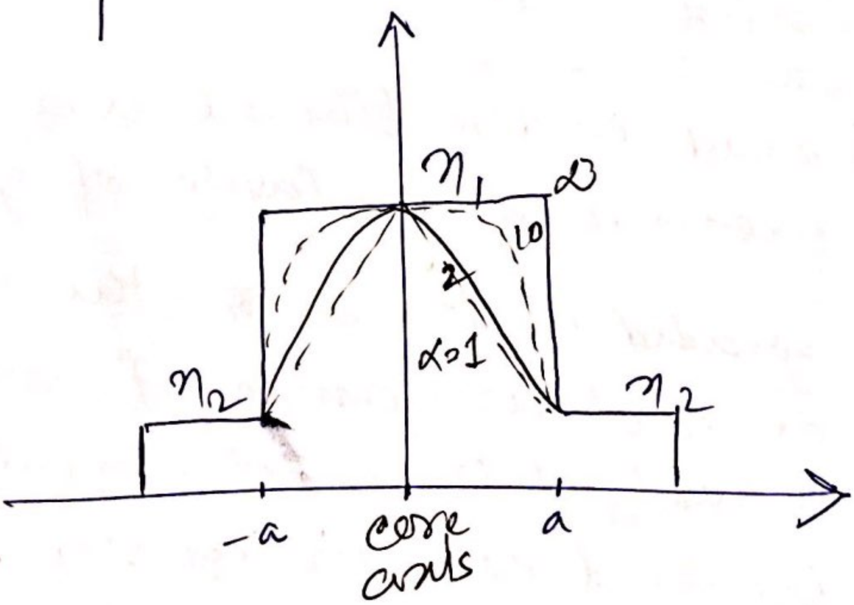
Δ = refractive index difference
α = shape of ~~the~~ index profile.
r = radial distance from the fiber axis.





8

Q. A multimode step index fiber with a core diameter of 80μm and a relative index difference of 1.5% is operating at a wavelength of 0.85 μm. If the core refractive index is 1.48, estimate

(a) The normalize freqn. for the fiber.

(b) The number of guided modes

⟹ given. $\lambda = 0.85 \times 10^{-6}$ m.

$a = 40 \mu m$.

$n_1 = 1.48$

$\Delta = 0.015$

$$V = \frac{2\pi}{\lambda} a n_1 (2\Delta)^{\frac{1}{2}}$$

$$= \frac{2\pi \times 40 \times 10^{-6} \times 1.48 \times (2 \times 0.015)^{\frac{1}{2}}}{0.85 \times 10^{-6}}$$

$$= 75.8$$

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(b) guided Mode

$$M. = \frac{v^2}{2}$$

$= 2873$

(2)

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4) Q. A step index multimode fiber with a numerical aperture of a 0.20, supports approximately 1000 modes at an 850nm wave length.

(a) What is the diameter of the core.

(2) How many modes does the fiber support at 1320nm

(3) " " " " " " at 1550nm

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⟹ NA = 0.20

M = 1000

λ = 850 nm.

(a) $V^2 = 2M$

$\Rightarrow V = \sqrt{2M}$

$= \sqrt{2000}$

$= 44.72$

$V = \frac{2\pi}{\lambda} a . NA$

$\Rightarrow a = \frac{V\lambda}{2\pi NA} = \frac{44.72 \times 850 \times 10^{-9}}{2 \times 3.14 \times 0.20}$ m.

$= 30.264 \times 10^{-6}$ m.

diameter of the core = 60.53 μm.

(b) $V = \frac{2\pi}{\lambda} \times 30.264 \times 10^{-6} \times 0.20$ (λ = 1320 nm)

$= 28.8$

$M = \frac{V^2}{2} = 414.62$

(c) $V = \frac{2\pi}{\lambda} \times 30.264 \times 10^{-6} \times 0.20$

$= 24.51$

M = 300.30

10

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Photonic Crystal Fibers:-

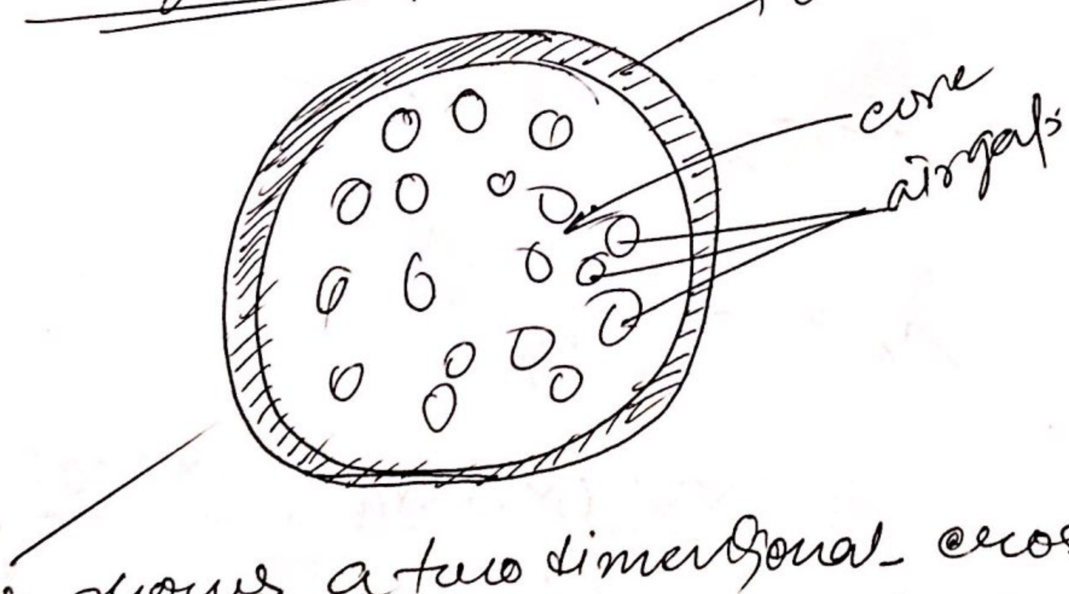
Initially this was called as Holey fiber and later became known as photonic crystal fiber (PCF) ~~as~~ a or a microstructure fiber.

The two types of pcf are

① Index - Guided - microstructures.

② Photonic bandgap fiber.

① Index guided PCF:-



→ Fig shows a two dimensional cross-sectional end view of the structure of an index guided PCF.

→ The fiber has a solid core that is surrounded by a cladding region which contains air holes running along the length of the fiber.

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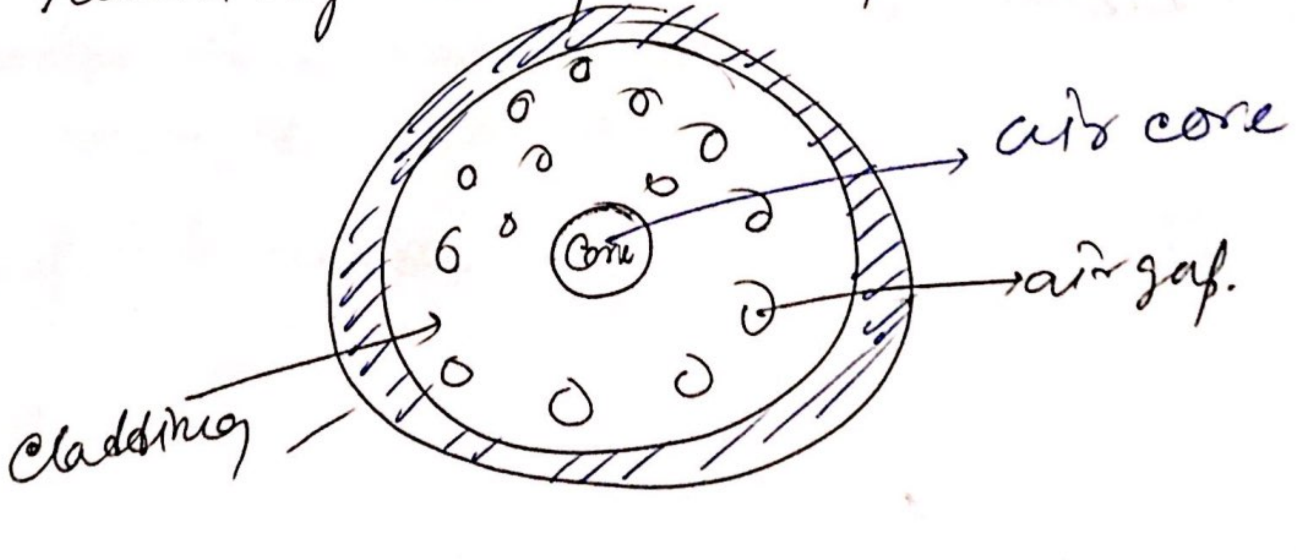
→ The advantages of these fibers are they provides very low losses and they have the ability to transmit high optical power levels ~~and a high resistance.~~ to

② Photonic Band-gap:

→ The figure shows a two dimensional cross sectional end view of ~~the~~ a photonic band gap fiber.

→ Here in contrast to an index guiding PCF, there the fiber has a hollow core that is surrounded by a cladding region which contains air holes running along the length of the fiber.



* The functional- principle of photonic bandgap fiber is analogous to the role of a periodic crystalline lattice in a semiconductor, which blocks ~~electronics~~ electrons from occupying a bandgap-region.

→ In PBG fiber the hollow core acts as a defect in the photonic band gap structure, which creates a region in which light can propagate

(6)

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Q. A multimode step index fiber has a refractive index difference of 1% and a core refractive index of 1.5. The number of modes propagating at a wavelength of 1.3 μm is 1100. Estimate the diameter of the fiber core.

Solution:-

$\Delta = 1\%$

$= 0.01$

$n_1 = 1.5$

$\lambda = 1.3 \mu m$

$M = 1100$

For step index fiber

$\therefore M = \frac{V^2}{2}$

$\Rightarrow V^2 = 2.M$

$= 2200$

$\therefore V = \sqrt{2200} = 46.90$

$\therefore V = \frac{2\pi}{\lambda} a \, n_1 \sqrt{2\Delta}$

$\Rightarrow a = \frac{\lambda V}{2\pi n_1 \sqrt{2\Delta}}$

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$\therefore a = \dfrac{1.3 \times 10^{-6} \times 46.90}{2 \times 3.14 \times 1.05 \times \sqrt{2 \times 0.01}}$

$= \dfrac{60.97 \times 10^{-6}}{0.1332}$

(4) $= 457.66 \mu m$.

$\therefore$ Diameter $= 915.33 \mu m$.

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