Module: V

FIBER OPTICS

Syllabus: Introduction to fiber optics - Total Internal Reflection - Critical angle of propagation - Acceptance angle - Numerical Aperture – V number (qualitative) - Classification of fibers based on Refractive index profile, modes - Applications of optical fibers – Fiber optic Sensors (temperature, displacement).

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Introduction:

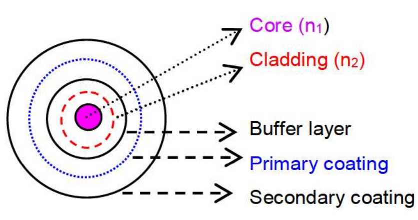
An optical fiber is a cylindrical transparent dielectric material, which guides light waves along its length by total internal reflections. Optical fibers play an important role in communication systems. Optical fiber requires a light source, for launching light into the fiber at one end and a photodetector at another end. The communication system mainly consists of 3 parts. (i) Transmitter (ii) Transmission Channel (iii) Receiver. In 1966 Charles and coworkers demonstrated the transmission of information over glass fiber, but they observed attenuation losses while sending information. With the development of Lasers, there is a tremendous change in the communication system. A cable may contain one to several hundreds of such fibers.

** Optical fiber construction (or) Structure of Optical fiber:

An optical fiber is thin long transparent dielectric material made up of glass/plastic, which guides light waves along its length by total internal reflections (in optical frequency).

Optical fiber mainly consists of core and cladding regions. Let n_1 & n_2 be the refractive indices of core and cladding regions. In general, the refractive indices of the core are greater than the cladding region [$n_1 > n_2$]. In an optical fiber, the core is an innermost cylindrical region that guides light along with its length and is surrounded by another coaxial cylindrical region called cladding, it helps to keep the light within the core region (prevents the leakage of light). These regions are covered with a buffer layer, which gives physical and environmental protection. For greater strength and protection of the fiber, a soft plastic coating (primary coating) is done. Finally, it is covered with a hard dielectric material called the secondary layer. For getting quality transmission cladding region is coated with silica.

In general, the diameter of the core is between 5 - 75 μm and the cladding is 20 – 125 μm.



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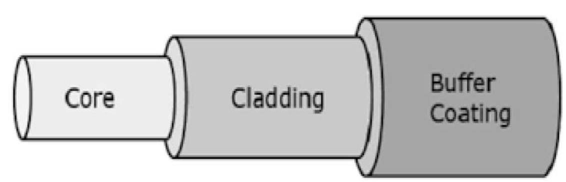
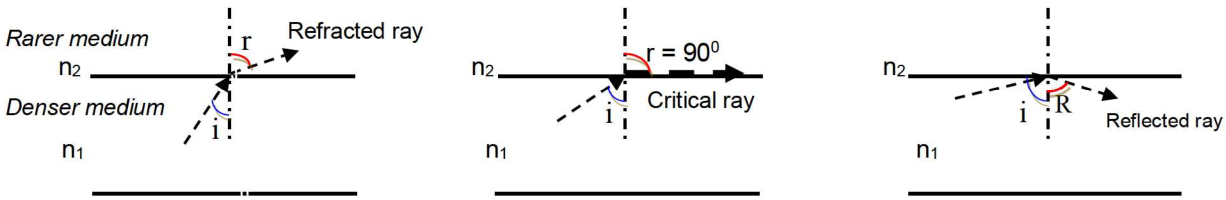


Parts of an Optical fiber

** Principle of Optical Fiber (or) Total Internal Reflection:

An optical fiber is a hair-thin cylindrical fiber made of glass (or) transparent dielectric material. Optical fiber consists of core and cladding regions. Let n_1 & n_2 be the refractive indices of core and cladding regions. In general, the refractive index of the core region is greater than the cladding region [$n_1 > n_2$]. When light rays travel from the core region to the cladding region, refraction takes place. Since the ray travel from a denser medium to a rarer medium, the angle of refraction is greater than the angle of incidence *(shown in Fig. A)*. With the increase in the angle of incidence, the angle of refraction also increases. *At a particular angle of incidence (**i**) the refracted ray just passes through the core & cladding interface (Fig. B), that angle of incidence is called the* ***Critical angle (θ_c).*** *[At a particular angle of incidence, the angle of refraction is 90° then that incidence angle is called the critical angle (Fig. B)].* With a further increase in the incidence angle, the ray is reflected back to the core region *(Fig. C)*, this phenomenon is called ***total internal reflection***. This is the principle is involved in optical fiber.



(Fig. A) $i < \theta_c$ (Fig. B) $i = \theta_c$ (Fig. C) $i > \theta_c$

Applying Snell's law to the 2 media (Fig. B)

$$n_1 \sin i = n_2 \sin r$$

$$n_1 \sin \theta_c = n_2 \sin 90° \text{ (Fig. B)}$$

$$n_1 \sin \theta_c = n_2$$

$$\sin \theta_c = \frac{n_2}{n_1} \rightarrow \boxed{\text{Critical Angle } (\theta_c) = \sin^{-1}\left(\frac{n_2}{n_1}\right)}$$

Condition for total internal reflections:

1. light should move from denser medium to rarer medium
2. When $i > \theta_c$ light rays reflected back to the denser medium and got total internal reflection.

** Acceptance angle & Acceptance cone:

Let a light beam incident at one end of the optical fiber, the entire light beam may not pass through the core region. Only the rays which make the angle of incidence greater than the critical angle (θ_c) these rays undergo total internal reflections and propagate through the core region. The other rays are refracted through the cladding region and are lost. *But at a particular angle of incidence the entire light beam undergoes total internal reflection, that angle is known as the acceptance angle* (θ_0).

Optical fiber consists of core and cladding regions. Let n_o, n_1 & n_2 be the refractive indices of air, core, and cladding regions. Let a beam of light incident at 'A' where light travels from the air (n_o) to the core region (n_1), later the light ray reaches point 'B' and passes through the core and cladding interface (BC).

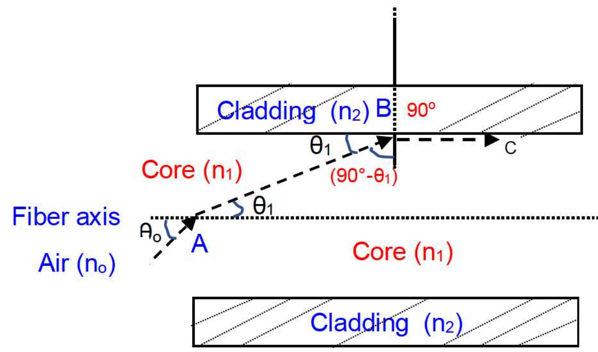


Fig. 1

Applying Snell's law at 'B'

$$n_1 \sin(90^\circ - \theta_1) = n_2 \sin 90^\circ$$

$$n_1 \sin\theta_c = n_2 \quad [\because (90^\circ - \theta_1) = \theta_c]$$

$$\sin\theta_c = \frac{n_2}{n_1} \qquad \text{------ (1)}$$

Applying Snell's law at 'A'

$$n_o \sin\theta_o = n_1 \sin\theta_1$$

(At A, light travels from rarer medium to denser medium, and the angle of refraction is less than the angle of incidence)

$$\sin\theta_o = \frac{n_1}{n_0} \sin\theta_1 \qquad \text{------ (2)}$$

From Fig., at B, $\theta_1 + (90^\circ - \theta_1) = 90^\circ$

$$\theta_1 + \theta_c = 90^\circ$$

$$\theta_1 = 90^\circ - \theta_c \qquad \text{------ (3)}$$

Substituting Eq. (3) in eq. (2)

$$\sin\theta_o = \frac{n_1}{n_0} \sin(90^\circ - \theta_c)$$

$$\sin\theta_o = \frac{n_1}{n_0} \cos\theta_c \qquad \text{----- (4)}$$

$$\cos\theta_c = \sqrt{1 - \sin^2\theta_c} = \sqrt{1 - \frac{n_2^2}{n_1^2}} \qquad [\because \text{Eq.(1)}]$$

Substituting above Eq. in Eq. (4)

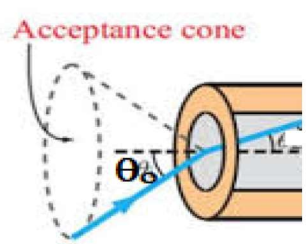
$$\sin\theta_o = \frac{n_1}{n_0}\sqrt{1 - \frac{n_2^2}{n_1^2}}$$

$$\sin\theta_o = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \qquad \text{------ (5)}$$

Here n_o is refractive index of air *(i.e. $n_o = 1$)*

$$\sin\theta_o = \sqrt{n_1^2 - n_2^2} \qquad \text{------ (6)}$$

$$\theta_o = \sin^{-1}\sqrt{n_1^2 - n_2^2}$$



This maximum angle is called the acceptance angle.

Fig.2

The rotating the acceptance angle about the fiber axis, we get an incident cone with a semi-vertical angle θ_o. This incident light cone at the core of the optical fiber will be accepted by the fiber for guidance through it, which is known as the acceptance cone *(Shown in Fig.2)*.

$$\boxed{\text{Acceptance cone} = 2\,\theta_o}$$

** Numerical Aperture:

The numerical aperture represents the light-gathering capacity of an optical fiber. The Light gathering capacity is proportional to the acceptance angle (θ_o).

"Sine of maximum acceptance angle is called the numerical aperture (NA) of the fiber"

$$\boxed{\mathbf{NA = Sin\ \theta_{o\,(Max)}} = \sqrt{n_1^2 - n_2^2}} \qquad \text{------ (7)}$$

Let n_1 & n_2 be the refractive indices of core and cladding regions. In general, the refractive index of the core region is greater than the cladding region [$n_1 > n_2$].

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

$$= \sqrt{(n_1 + n_2)\,(n_1 - n_2)} \qquad \text{------ (8)}$$

Let the fractional change in refractive index (Δ) is the ratio between the difference in refractive indices of the core and cladding to the refractive index of the core.

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$\Delta\, n_1 = (n_1 - n_2) \qquad \text{------ (9)}$$

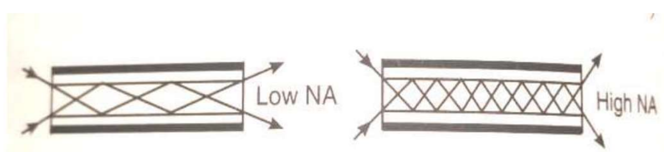


Fig. Illustration of the propagation of light though low & High numerical aperture fibers

Substituting Eq. (9) in Eq. (8)

$$\text{Sin}\ \theta_o = \sqrt{\Delta\, n_1\, (n_1 + n_2)}$$

In most of fibers $n_1 \approx n_2$ $\rightarrow n_1 + n_2 = 2n_1$

The above equation becomes $\text{Sin}\ \theta_o = \sqrt{\Delta\, n_1\, (2n_1)} \; = \; = \sqrt{2\,\Delta\, n_1^2}$

$$\boxed{\mathbf{NA = Sin\ \theta_{o\,(Max)} = n_1 \sqrt{2\,\Delta}}}$$

The light collecting capacity depends on the refractive index of core and cladding materials and is not a function of the fiber dimensions. *The range of numerical aperture is from 0.13 to 0.5.*

** V-number (or) Normalized frequency:

V-Number determines how many modes a fiber can support (or) The total number of modes traveling in a fiber depends on the V-Number.

$$V = \frac{\pi d}{\lambda}\,\text{NA}$$

where d is the diameter of the core, λ is the wavelength of light used and NA is the numerical aperture of the fiber

$$V = \frac{\pi d}{\lambda} \sqrt{n_1^2 - n_2^2} \quad \text{(or)} \quad V = \frac{\pi d}{\lambda} n_1 \sqrt{2\Delta}$$

For single-mode fiber $V \leq 2.405$ & for multimode fiber $V > 2.405$.

Number of modes through step-index fiber $= \frac{V^2}{2}$

Number of modes through GRIN fiber $= \frac{V^2}{4}$

** Classification of optical fibers (or) Types of optical fibers :

Optical fibers are classified into 3 types.

i) Based on the modes ii) Based on the refractive index iii) Based on the materials

Based on the Modes:

Based on the number of modes of propagation, the optical fibers are classified into two 2 types.

1) Single-mode fiber (SMF) 2) Multimode fiber (MMF)

Note: Mode means, the number of paths available for light propagation in a fiber.

1) Single-mode fiber (SMF):

The core diameter of the fiber is about 2-8 μm and the outer diameter of the cladding region is about 60 - 70 μm *(Thin core and thick cladding diameters)*. Let n_1 & n_2 be the refractive indices of core and cladding regions. The refractive indices differences are very small. In a single-mode fiber, only one mode can propagate through the fiber and there is no degradation of the signal during travel. In this cable, the transmission capacity of optical fiber is inversely proportional to dispersion, hence it is used fully in long-distance communication. Fabrications of such types of cables are difficult and hence they are costly. *The general core is made up of silica doped with germanium and the cladding is made up of silica lightly doped with phosphorus oxide.*

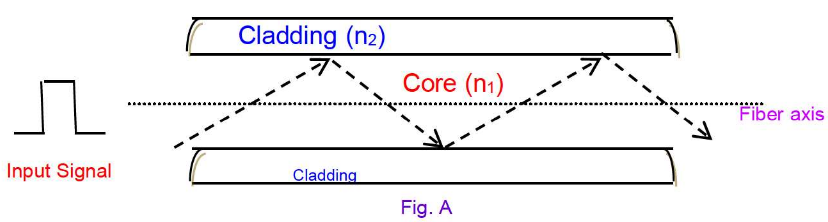
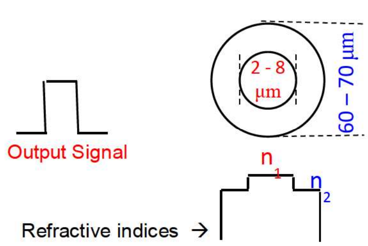


Fig. A

Fig. B



The ray propagation of SMF is shown in Fig. A and the cross-sectional view is shown in Fig. B. In SMF, the Numerical aperture (NA) and the fractional change in refractive indices (Δ) are very small. The low 'NA' means the acceptance angle is also low. Therefore, light coupling into the fiber is difficult, hence costly laser diodes are needed to launch light into the SMF.

Nearly 80% of the fibers manufactured today in the world are SMF. These are used in communication underwater cables, and submarine cable systems.

Advantages:

i) No degradation of signal, ii) High data transfer rate,

iii) Highly suitable for communications, iv) High bandwidth (3000 MHz).

Disadvantages:

i) Only one mode of propagation, ii) Cables are costly, iii) Launching of light into fiber is difficult, iv) Laser source is required for launching light in fiber, v) Coupling of cable is difficult.

2) ***Multimode fiber*** **(MMF):**

It has a large core diameter (40 μm) and cladding diameter (125 μm). The refractive indices difference is larger than SMF. It allows a large number of modes to propagate through it, hence there is signal degradation. They don't suitable for long-distance communication due to large dispersion. Fabrications of such type cables are easy and hence they are low cost. These are used in data links.

When the light rays enter at one end of the optical fiber, they come out from another end at different times. The path distances of the rays are different. The light ray-1 makes a greater angle with the fiber axis and suffers several reflections through the fiber (travels a long distance). The light ray-2 makes a lesser angle with the fiber axis and suffers less reflection within a short time. Due to the path difference between these rays when they superimpose to form the output signals, the signals are overlapped. This signal distortion is known as ***intermodal dispersions***. It is difficult to retrieve the information carried by the distorted output signals. In Multi-mode fiber/ Multimode step-index fiber, the propagation of light rays is due to multi reflections so it is a ***reflective type***.

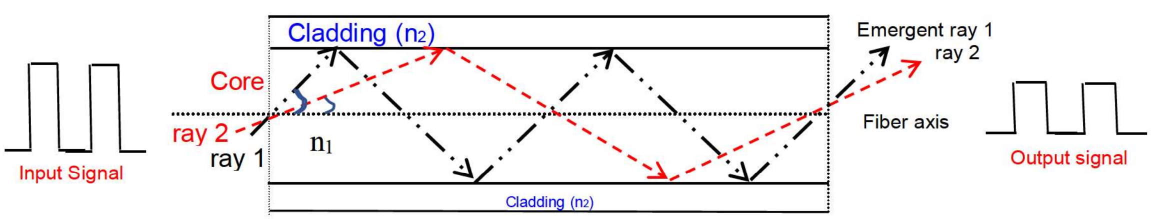
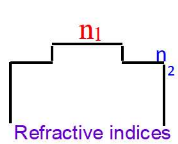


Fig. A



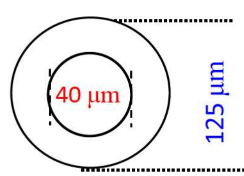


Fig. B Fig. C

NA is a little bit high compared with single-mode fiber. The ray's propagation in MMF is shown in Fig. A and the cross-sectional view is shown in Fig. C.

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Advantages:

i) Less expensive, ii) LED / Laser source can be used as a source of light for launching light into MMF, iii) Launching of light is easier, iv) coupling of MMF with other fibers are easy.

Disadvantages:

i) Degrades signal, ii) Less suitable for communications, iii) Low bandwidth (< 200 MHz).

Based on the refractive index:

Based on the refractive index profile, optical fibers are divided into 2 types

1) Step-index optical fiber 2) Graded index optical fiber

1) *Step - index optical fiber:*

Step index optical fiber is also called multimode step-index optical fiber. In this optical fiber, the refractive index of the core is constant along the radial direction and abruptly falls to a lower value at the cladding region. Let 'n_1, n_2' be the refractive indices of core and cladding regions ($n_1 > n_2$) with radii 'a, b'. The core has a diameter of 50 to 200 μm and the cladding has a diameter of 100 to 250 μm. The diameter of the core region is large, so the number of propagations of light can be possible.

The light rays enter at one end of the optical fiber and come out from another end. In fig. two rays are entering at different angles of incidence with the fiber axis, the 2 rays travel different path lengths and emerge out at different times. The light ray-1 makes a greater angle with the fiber axis and suffers several reflections through the fiber (travels a long distance). The light ray-2 makes a lesser angle with the fiber axis and suffers less reflection within a short time. Due to the path difference between these rays when they superimpose to form the output signals, the signals are overlapped. This signal distortion is known as ***intermodal dispersions***. It is difficult to retrieve the information carried by the distorted output signals. In step-index fiber/ Multimode step-index fiber, the propagation of light rays is due to multi reflections so it is a ***reflective type***. The light passing through the optical fiber is in a zig-zag manner.

Number of modes through step-index fiber = $\frac{V^2}{2}$

$$V = \frac{\pi d}{\lambda} NA \quad \text{(or)} \quad V = \frac{\pi d}{\lambda} \sqrt{n_1^2 - n_2^2}$$

Where 'd' = diameter of core, 'NA' = Numerical aperture 'λ' = Wavelength of light

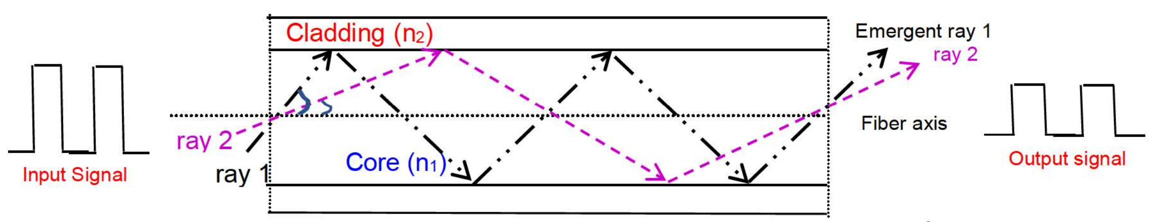

Fig. A

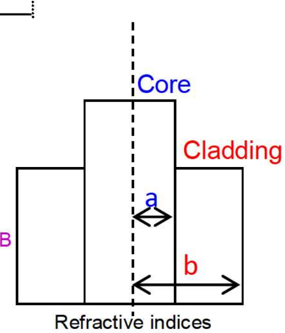

Fig. B

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Advantages:

i) Manufacture of such type of cables is easy and is less expensive. ii) LED / Laser source can be used as light source, iii) Launching of light is easier, iv) coupling of these fibers is easy.

Disadvantages:

i) Due to high dispersion data rate is lower and transmission is less efficient,

ii) Less suitable for communications, iii) Low bandwidth (< 200 MHz).

2) ***Graded-index optical fiber*** **(GRIN):**

In this optical fiber, the core has a non-uniform refractive index *(Refractive index is maximum at the center and decreases parabolically from the fiber axis)* and the cladding has a uniform refractive index. Let a & b be the radii of core & cladding. The core has a diameter of 50 to 200 μm and the cladding has a diameter of 100 to 250 μm. The diameter of the core region is large so the number of propagations of light can be possible.

Let n_1 ($n_a > n_b > n_c > \ldots.. > n_n$) and n_2 be the refractive indices of core and cladding regions. As the light ray goes from the region of the higher refractive index to the region of the lower refractive index, it is bent away from the normal (refraction takes place). This process is continued till the condition for total internal reflection is met/satisfied. Later the ray travels back toward the core region and again is continuously refracted. As result, the light rays travel in a helical manner. The ray propagation of graded-index optical fiber is shown in Fig. A. The propagation of light rays in GRIN is a ***refractive type***.

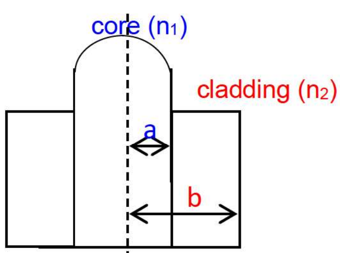
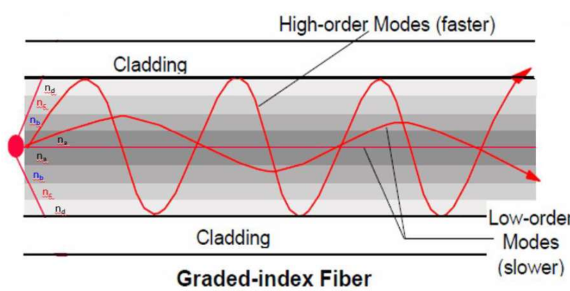
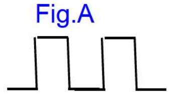


Fig.A

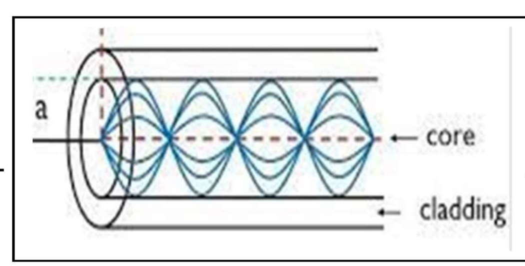


(Or)

Fig.A



Input Signal



Output Signal

The light rays enter at one end of the optical fiber, they come out from another end at the same time. The incident rays making different angles with the axis enter into the fiber, they adjust their velocities due to variation of refractive index and emerging out from the fiber.

i.e. The velocity of light is different at different parts of the fiber. The near-surface of the core refractive index is minimum, so rays travel faster than rays travel at the center. Hence the rays come out at approximately the same time.

Number of modes through GRIN fiber $= \dfrac{V^2}{4}$

$$V = \frac{\pi d}{\lambda} NA \quad \text{(or)} \quad V = \frac{\pi d}{\lambda} \sqrt{n_1^2 - n_2^2}$$

Where 'd' = diameter of core, 'NA' = Numerical aperture 'λ' = Wavelength of light

In general, these cables are used in telephone lines. GRIN fiber is a refractive type of optical fiber.

Advantages:

i) Either LED / Laser source can be used as a source of light with GRIN fibers

ii) Launching of light is easier

iii) Attenuation of loss of light is less

iv) Bandwidth is 200 MHz-km to 3 GHz-km

Disadvantages:

i) Manufacture of such types of cables is more complex. Hence, they are expensive.

ii) Coupling of cables is difficult.

Based on the materials:

Based on the materials, optical fibers are further divided into 2 types.

i.e. Glass fibers and plastic fibers. Further, these are divided into

i. Glass core, Glass cladding ii. Glass core, Plastic cladding iii. Plastic core, plastic cladding

(Step index fibers are produced in three common forms)

The basic material for the fabrication of glass fiber is silica (SiO_2) / silicates, it has a refractive index of 1.458 at λ = 850 nm. By adding dopants to silica, the refractive index may increase / decrease. For increasing the refractive index GeO_2, P_2O_5 is added to silica, and for decreasing the refractive index B_2O_3, fluorides are added.

Plastic fibers are very cheap and high mechanical flexible. The main disadvantages are they withstand up to 80 °C and dispersion is large. Hence, they are used in low-cost applications.

Ex. for plastic fiber:

i. PMMA (Polymethyl methacrylate) core ($n_1 = 1.49$) & cladding made of its copolymer ($n_2 = 1.4$).

ii. Polystyrene core ($n_1 = 1.60$) & methyl methacrylate cladding ($n_2 = 1.49$)

In general, fiber size is expressed by 50/125, which means the core diameter is 50 μm and the cladding diameter is 125 μm.

Comparison of different types of fibers: (Consolidated table)

S.No.	Feature	SMF	MMF	GRIN
1.	*Typical Core diameter*	10 μm	50 to 200	50 to 200 μm
2	*Fractional refractive index change (Δ)*	Very small	Large	
3	*Numerical Aperture* (NA)	Small	Large	Smaller than MMF
4	*Number of Modes*	Only one mode	Many Modes	Many Modes
5	*Attenuation*	Least	High	Lower
6	*Dispersion*	Zero intermodal dispersion	Large	Zero intermodal dispersion. But material dispersion exists
7	*Bandwidth*	> 3 GHz-km	< 200 MHz-km	200 MHz-km to 3 GHz-km
8	*Advantages*	No degradation of signal, High data transfer rate, Highly suitable for communication	Less expensive, LED/Laser source can be used for launching light into the fiber, Coupling of fibers is easy.	LED/Laser source can be used for launching light into the fiber
9	*Disadvantages*	Cables are expensive, Coupling is difficult, and Launching light into fiber is difficult	Degrades signal, Less suitable for communication	Manufacturing is complex, Cables are costly, Coupling is difficult
10	*Applications*	Underwater cables, Suitable for communications	Data Links	Telephone Lines

* <u>Advantages of optical fibers in communications</u>:

1. Optical fibers are quite cheap.
2. Fibers are insulators, there is no scope for getting electrical shocks.
3. At a temperature of 800 °C glass fibers are unaffected.
4. Corrosion due to water and chemicals being less than copper.
5. Fibers are made up of glass, and the raw materials of glass (silica) are available on earth.
6. Fibers are insulating materials, hence minimizing cable thefts.
7. Single optical fiber transfer large data in a short duration
8. They have a very wide bandwidth and high accuracy.
9. Transmission rate is high since communication waves travel with optical frequency (10^{15} Hz).
10. Longer life span (about 30 years).
11. Optical fibers are more reliable/easily maintained than copper cables.
12. They possess low transmission loss and noise-free transmission.
13. No cross talks/overlapping of the signals in the fibers.

** <u>Applications of optical fibers</u>:

1. Optical fibers are used in communication systems.
2. It is used to transmit a large number of TV signals in digital form.
3. Optical fibers are used in endoscopes and bloodless surgeries.
4. These are used for removing the small blood blocking the heart, and kidneys….
5. In the treatment of cancer therapy (IR is transmitted through the fiber cables and destroys the cancerous cells.)

6. Optical fibers are used in space vehicles, submarines, etc…
7. These are used in supercomputers, and radars.
8. These are used as sensors (for measuring physical parameters like pressure, temperature, strain, magnetic field, acoustic field, liquid flow, moisture, etc….)
9. Glass fiber withstands up to 800 °C, hence they are used in industry fire alarm systems.
10. Optical fibers are used in military applications.
(Aircraft and ships need tons of copper wire for communication equipment. For example, a shipboard radar system requires about 250 m cables with a weight of about 7 Tones, if these cables are replaced with optical fiber weighing 200 kg.)
11. They are used for guiding weapons and submarine communication system.

Note: **Properties of optical fiber:**

i. These are small in size, less weight, flexible, and mechanically strong.
ii. They have a very wide bandwidth and high accuracy.

Disadvantages of Optical fibers:

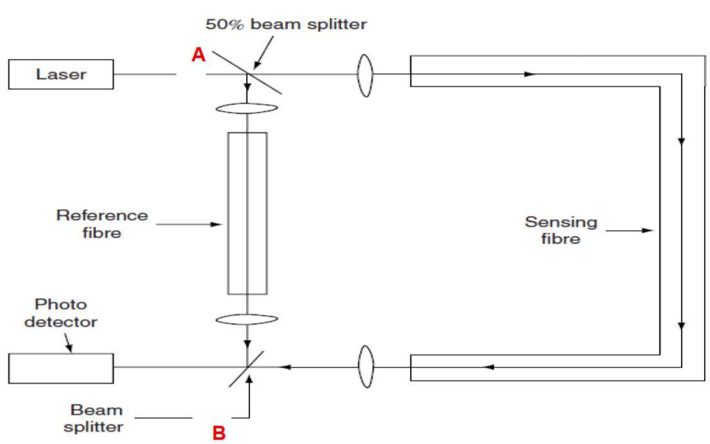
i. Installation and maintenance of optical fibers require a new set of skills.
ii. They require specialized and costly equipment. iii. The initial investment is high.

** Fiber optic Sensors:

Sensors are devices used to measure/monitor quantities such as displacement, pressure, temperature, flow rate, liquid level, etc. Sensors developed using fibers are more sensitive and reliable.

i. Temperature sensor / Pressure sensor:

The light coming from the laser is divided into two rays with a beam splitter (A). One beam (50%) passes through the sensing fiber, and another beam (50%) through the reference fiber, the two beams were superimposed using another beam splitter (B) and caused an interference pattern.



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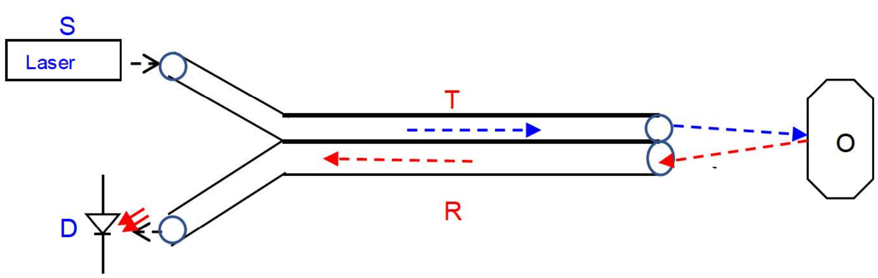
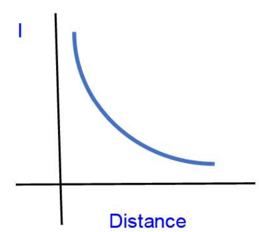
The intensity of the fringes depends on the phase relation between the two waves. If the sensing fiber is subjected to temperature / pressure, as result the refractive index changes / length changes, which causes a change in the phase of light at the end of the fiber. The phase change is directly proportional to the magnitude of the change in pressure / temperature. If the waves are in phase, then the intensity is maximum; this happens when the sensing fiber is not disturbed. The intensity is minimum if the waves are out of phase due to a $\lambda/2$ change in the length of the sensing fiber. The intensity of interference fringes can be measured with a photodetector and temperature or pressure changes can be measured.

ii. Displacement Sensor:

The displacement sensor consists of a light source ‘S’, transmitting fiber ‘T’, receiving fiber ‘R’, an object ‘O’, and the detector ‘D’. The fibers ‘T & R’ are coupled properly to the source and detector. The light from the laser source is passing through fiber cable ‘T’ and is incident on the moving object. The light is reflected from the moving object ‘O’ and incident on the receiving fiber (R) and transmitted to a detector. The intensity of the light collected depends on how far the reflecting targets are from the fiber optic probe. Fig. shows the detected light intensity versus distance from the target. The accuracy depends on the probe configuration. If there is increasing in the intensity of light (which is noticed by the detector), the object is moving toward the sensor. If there is decreasing in the intensity, the object moving away from the sensor





Note: If a bimetallic strip is attached to the reflecting surface in the displacement sensor it serves as a temperature sensor.

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Calculate the angle of acceptance of a given optical fibre, if the refractive indices of the core and cladding are 1.563 and 1.498, respectively.

Refractive index of core (n_1) = 1.563

Refractive index of cladding (n_2) = 1.498

θ_o = ?

$$\theta_0 = \sin^{-1}\sqrt{n_1^2 - n_2^2}$$

$$NA = \sin\theta_0 = \sqrt{n_1^2 - n_2^2}$$

$$= \sqrt{1.563^2 - 1.498^2} = 0.446$$

Acceptance angle $= \sin^{-1}(0.446) = 26°30'$.

A fibre has the core and cladding refractive indices 1.45 and 1.44 respectively. Find the relative refractive index difference.

Refractive index of core (n_1) = 1.45

Refractive index of cladding (n_2) = 1.44

Δ = ?

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$= \frac{1.45 - 1.44}{1.45} = 6.896 \times 10^{-3}$$

= 0.0069

An optical fibre has a core material of refractive index 1.55 and cladding material of refractive index 1.50. Calculate its numerical aperture.

Refractive index of core (n_1) = 1.55

Refractive index of cladding (n_2) = 1.50

NA = ?

$$\boxed{NA = \sin\theta_{0\,(Max)} = \sqrt{n_1^2 - n_2^2}}$$

$$= \sqrt{1.55^2 - 1.50^2} = 0.3905$$

In an optical fibre, the core material has refractive index 1.6 and refractive index of clad material is 1.3. what is the value of critical angle? Also find the value of angle of acceptance cone.

$n_1 = 1.6$ $n_2 = 1.3$ $\theta_c = ?$ $2\theta_o = ?$

$$\text{Critical Angle } (\theta_c) = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$\theta_c = \sin^{-1}(1.3/1.6)$$

$$\theta_c = 54.3^\circ$$

$$\theta_0 = \sin^{-1}\sqrt{n_1^2 - n_2^2}$$

$$= \sin^{-1}\left[\sqrt{1.6^2 - 1.3^2}\right]$$

$$= \sin^{-1}(0.87)$$

$$= 60.5^\circ$$

Acceptance cone = 2 θ_0

Acceptance cone = 2 x 60.5 = 121°

The refractive indices of core and cladding materials of a step index fibre are 1.48 and 1.45, respectively. Calculate the critical angle at the core-cladding interface and fractional refractive indices change.

Refractive index of core (n_1) = 1.48

Refractive index of cladding (n_2) = 1.45

$\theta_c = ?$ $\Delta = ?$

$$\text{Critical Angle } (\theta_c) = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$\theta_c = \sin^{-1}\frac{n_2}{n_1} = \sin^{-1}\left(\frac{1.45}{1.48}\right) = 78^\circ 26'$$

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$= \frac{1.48 - 1.45}{1.48} = 0.02$$

The refractive index of core of step index fibre is 1.50 and the fractional change in refractive index is 4 %. Estimate: (i) refractive index of cladding, (ii) numerical aperture, (iii) acceptance angle in air and (iv) the critical angle at the core- cladding interface.

Refractive index of core (n_1) = 1.50 $\Delta = 4\% = {}^4/_{100} = 0.04$

$n_2 = ?$ NA = ? $\theta_o = ?$ $\theta_c = ?$

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$\Delta n_1 = (n_1 - n_2)$$

$0.04 \times 1.5 = 1.5 - n_2$

$n_2 = 1.5 - 0.06$

$n_2 = 1.44$

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

$$= \sqrt{(1.5)^2 - (1.44)^2} = \sqrt{2.25 - 2.0736} = \sqrt{0.1764} = 0.42$$

$$\text{Acceptance angle, } \theta_0 = \sin^{-1}(\text{NA})$$

$$= \sin^{-1}(0.42) = 24^\circ 50'$$

$$\text{Critical angle, } \theta_c = \sin^{-1}\frac{n_2}{n_1}$$

$$\sin^{-1}\frac{1.44}{1.50} = \sin^{-1} 0.96 = 73^\circ 44'$$

Calculate the V-number and number of modes propagating through the fiber having radius 50 μm. The refractive indices of core and cladding regions are 1.53 and 1.50 respectively. The wavelength of light source is 1μm.

$n_1 = 1.53$ $n_2 = 1.50$ $\lambda = 1\mu m$ $a = 50$ μm V=? Modes = ?

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

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$$

$$= \frac{2\times 3.142\times 50}{1}\left(1.53^2 - 1.50^2\right)^{\frac{1}{2}}$$

$$= 94.72$$

Number of modes through step index optical fiber is $\frac{V^2}{2}$

Number of modes through Graded index optical fiber is $\frac{V^2}{4}$

$$\text{No. of modes } = \frac{V^2}{2} = \frac{94.72^2}{2} = 4486$$

No. of modes = 4486

Calculate the refractive indices of core and cladding of an optical fibre with a numerical aperture of 0.33 and their fractional difference of refractive indices being 0.02.

NA = 0.33, $\Delta = 0.02$, $n_1 = ?$ $n_2 = ?$

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$\Delta n_1 = (n_1 - n_2)$$

$$0.02\, n_1 = n_1 - n_2$$

$$n_2 = (1 - 0.02)\, n_1$$

$$n_2 = 0.98\, n_1$$

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

$$0.33 = \sqrt{n_1^2 - (0.98 n_1)^2} = n_1 [1 - (0.98)^2]^{0.5}$$

$$0.33 = n_1 \times 0.198997$$

$$n_1 = 1.6583$$

$$n_2 = 0.98 \times 1.6583 = 1.625$$