Light Propagation in Optical Fibers

Light Propagation in Optical Fibers refers to the transmission of light through a fiber optic cable. In this process, light is sent through the core of the fiber optic cable and is transmitted over long distances with minimal attenuation or loss of signal. The light signal is typically generated by a laser or LED source and then sent through the fiber optic cable by means of internal reflection.

The core of the fiber optic cable is made up of a material that has a higher refractive index than the cladding layer surrounding it. This means that when light enters the core, it is reflected internally at the boundary between the core and the cladding, rather than being absorbed or scattered. This allows the light to travel through the fiber optic cable without losing its intensity or quality over long distances. One necessary condition for the propagation of light through the optical fibre is that the refractive index of the fiber must be higher than that of the surrounding medium.

Light Propagation in Optical Fibers Video Lecture

For more information about the propagation of light in optical fiber, you can refer to the following video available on the **Byjus Exam Prep** official youtube channel.

Key Points About Light Propagation in Optical Fibres

Key points are the highlights which explain the light propagation in optical fibers. Here a few points are explained that illustrate the light propagation in optical fibers.

- If there is an interaction between a material and light then we go for photon theory.
- When we deal with the transmission of optical signal or reception of optical signal then we go for wave theory.
- When we have to compare the behavior of light in two mediums then we go for ray theory.
- The primary application of fiber optic communications is in long-distance telephone systems.
- Because of the great attenuation of light in a fiber optic cable, repeater units are used to amplify and regenerate the signals over long distances.
- Because of the very high frequency of light compared to typical information signals, tremendous bandwidth is easily available.
- Light is an electromagnetic signal like a radio wave but is much higher in frequency. It can be used as a carrier for information signals.
- The angle at which light strikes a surface is called the angle of incidence. The angle at which light is reflected from a surface is called the angle of reflection. The angle of incidence is equal to the angle of reflection.
- When a light ray passes from one medium to another, it is bent. This is called refraction.
- The amount of refraction is called the index of refraction n and is the ratio of the speed of light in air to the speed of light in another medium, such as water, glass, or plastic. [n = 1

in air, n = 1.3 in water, n = 1.5 in glass]. n=c/v, the Value of the refractive index is always greater than or equal to 1.

Total Internal Reflection

Total Internal Reflection is a phenomenon that occurs when a light wave traveling in a medium encounters a boundary with a second medium that has a lower refractive index. If the angle of incidence of the light wave is greater than a certain critical angle, the light wave is reflected back into the original medium rather than being refracted or transmitted into the second medium.

Total Internal Reflection is commonly observed in fiber optic cables, where it is used to transmit light over long distances with minimal loss of signal. In a fiber optic cable, the core of the cable is made of a material with a higher refractive index than the cladding layer surrounding it. This means that when light enters the core, it is reflected internally at the boundary between the core and cladding, rather than being absorbed or scattered. This allows the light to travel through the fiber optic cable without losing its intensity or quality over long distances.

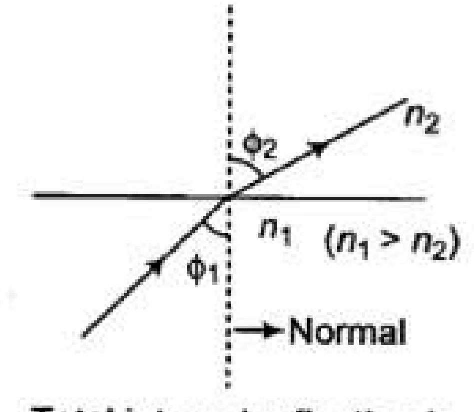
By Snell's law $n_1 \sin \varphi_1 = n_2 \sin \varphi_2$

if $\varphi_2 = 90$; internal reflection takes place

$\varphi_1 = \sin^{-1}(n_2/n_1)$

Total internal reflection will take place if the angle of incidence φ_1 will be greater than or equal to the critical angle.

$\varphi_c = \sin^{-1}(n_1/n_2)$



Total internal reflection in two mediums

Some Important Points About Total Internal Reflection

- The critical angle is the angle of incidence that causes the refracted light to travel along the interface between two different media.
- All the information in optical fiber is carried out by the principle of total internal reflection and all the information is carried in the core of the optical fiber.
- Cladding does not support any transmission of information.
- A popular fiber optic cable with a glass core and plastic cladding is called Plastic Clad Silica (PCS).
- The cladding surrounding the core protects the core and provides an interface with a controlled index of refraction.

Acceptance Angle (θ_a): Acceptance angle is the maximum angle to the fiber axis at which the light may enter in order to propagate.

Numerical Aperture (NA): It is a measure of the light-collecting ability of the fiber. It establishes the relationship between the acceptance angle and refractive indexes of the different mediums involved.

$n_0 \sin \theta_a = n_1 \sin(90 - \theta_c) = n_1 \cos \theta_c$

Relative Refractive Index Difference (Δ)

$NA = n_1(2\Delta)^{1/2}$

Meridional Rays: Meridional rays are those rays that pass through the core axis.

Skew Rays: Skew rays are those rays that do not pass through the core axis.

Step Index Fibre: The step-index means there is a sharp difference in the index of refraction between the core and cladding.

$n(r) = n_1 \quad r < a$

$n_2 \quad r \geq a$

Mode: Number of modes or mode volume $M = V^2/2$. Some modes depend on energy and phase equivalence is given below.

Key Points

- A single-mode cable is very small in diameter and essentially provides only a single path for light.
- Multimode cores are large and provide multiple paths for light.
- Multiple light paths through a step-index core cause a light pulse to be stretched and attenuated. This is called modal dispersion and it limits the upper pulse repetition rate and thus the information bandwidth.
- If we reduce the radius such that a single mode is only transmitted through the core so no dispersion and so no different delays

Graded Index Fibre: Graded index means that the index of refraction of the core varies over its cross-section, highest in the center and lowest at the edges.

Losses in Optical Fibre

The primary specification of a fiber optic cable is attenuation which is usually expressed as the loss in decibels per kilometer. Light loss in a fiber optic cable is caused by absorption, scattering, and dispersion.

Absorption Losses

Absorption losses can be classified as

- Intrinsic [due to interaction of one or major components of glass]
- Extrinsic [due to OH^- ion or due to transition element impurity]

Key Points

- Cable attenuation is directly proportional to its length.
- Cable losses at range from 1 dB/km in glass single-mode step-index cable to 100 dB/km for plastic multi-mode step-index cable.
- Fiber-optic cables can be spliced by gluing.

Critical Radius of Curvature

For multimode $$R_c = \frac{3n_1^2\pi}{4\pi\left(n_1^2 - n_2^2\right)^{3/2}}$$

For single mode $$R_c = \frac{20\lambda}{\left(n_1^2 - n_2^2\right)^{3/2}}\left[2.748 - 0.996\frac{\lambda}{\lambda_{min}}\right]^{-3}$$

Optical Sources

Fiber-optic systems use Light Emitting Diodes (LEDs) and semiconductor lasers as the main light sources. Laser is the source of monochromatic and coherent light. LED is the source of monochromatic and non-coherent light. Light-emitting diodes are used in short-distance, low-speed systems. Injection Laser Diodes (ILDs) are used in long-distance, high-speed systems.

Key Points

- In the case of the He-Ne laser for the same output optical power loss, input power is required compared to the Ruby laser.

- Most LEDs and ILDs emit light in the invisible near-infrared range (0.82 to 1.55μm)
- In the case of LED total recombination rate R_t is directly proportional to forward biased current.