# PHYSICAL SCIENCE
# STUDY OF SINGLE MODE FIBER

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***Abstract:-*** *Information carrying capacity in the single mode fiber is higher than other types of fibers (multimode step index, multimode graded index) The single mode fibers are the better option when the distance of communication is very high. Bandwidth requirement in this process is the primary concern. This fiber shows the better dispersion performance and hence has the higher bandwidth out of the fiber types*

***Keyword : -*** *Optical fiber, single mode fiber, multi mode fiber bandwidth, dispersion performance.*

**Introduction** :- An optical fiber is a non conductor wave guide that works at optical frequencies. This fiber wave guide is normally cylindrical in forms. Confines electromagnetic energy in the form of optical wave to within its surfaces and guides the light in a direction parallel to its axis. The communication characteristics of an optical wave guide are dictated by its organisation characteristics that have a vital effect in deciding how an optical signal is influenced as it transmitted along a fiber. Fiber optics technology involves the emission, transmission and detection of optical wave. In this paper discussion involves the fiber type, nature of optical wave and their interrelationships. Two methods are used to describe how an optical fiber guides optical wave. The ray optics involves concepts of reflection and refraction of optical wave to provide a better picture of the propagation mechanism. In second approach optical wave is treated as the electromagnetic wave which propagates along the axis of optical fiber wave guide. The main components of optical fiber system are the optical fibre itself as its transmission characteristics play a vital role for the performance of the whole system. The characteristics involve configuration of an optical fiber, optical wave propagating along the fiber, material used for fibers, loss mechanism in fiber and degree of dispersion of signal as it travels along the fiber. An optical fiber is a non conductor wave guide that works at optical frequencies. This fiber wave guide is normally cylindrical in forms. Confines electromagnetic energy in the form of optical wave to within its surfaces and guides the light in a direction parallel to its axis. The communication properties of an optical wave guide are dictated by its organization features that have a vital effect in determining how an optical signal is affected as it propagates along a fiber. In this paper, we have studied single mode fiber based on refractive index profile.

**Development :-** The transmission of light along wave guide may be outlined in terms of a set of guided em waves called the modes of waveguide. This guided modes are referred to as the bound or trapped modes of the waveguide. Every guided mode is a form of electric and magnetic field distributions that is repeated along the fiber at equal intervals. Only a specific discrete number of modes are efficient of propagating along the guide. These modes are those electromagnetic waves that gratify the homogeneous wave equation in the fiber and the boundary condition at the waveguide surfaces. Among many different organisations of the optical waveguide, the most commonly accepted configuration is the single solid non conductor cylinder of radius $a$ and index of refraction $n_1$ shown in Fig, 1.1. This cylinder is called as the core of the fiber. The core is surrounded by a solid dielectric cladding which has a refractive index $n_2$ that is less than $n_1$. Although, in principle, a cladding is not necessary for optical wave to propagate along the core of the fiber, it serves several purposes. The cladding reduces dispersion loss that results from non conductor discontinuities at the core surface, it helps mechanical strength to the fiber and it saves the core from absorbing surface contaminants with which it could come in contact.

In standard optical fibers the core material is highly pure silica glass ($SiO_2$) and is surrounded by a glass cladding. Greater–loss plastic – core fibers with plastic claddings are also in use. Besides this, most fibers are confined in an elastic, abrasion-resistant plastic material. This material adds further strengths to the fiber and mechanically isolates or buffers the fibers from small geometrical irregularities, distortions, or roughness of adjacent surfaces. These perturbations could otherwise cause scattering losses induced by random microscopic bends that can arise when the fibers are incorporated into cables or supported by other configuration. Variation in the material composition of the core give rise to the two commonly used fiber types shown in Fig.2. In the first case, refractive index of the core is uniform throughout and undergoes an abrupt change or step at the cladding boundary. This is called **step-index fiber**.

In second case, the core refractive index is made to vary as a function of the radial distance from the center of the fiber. This type is named as **graded-index fiber**.

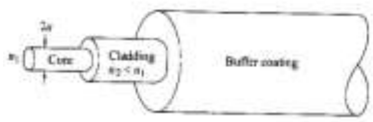


**Fig. 1**: Schematic of a conventional silica fiber structure. A circular solid core of refractive index $n_1$ is surrounded by a cladding having a refractive index $n_2$ less than $n_1$. An elastic plastic buffer encapsulates the fiber.

Both the step and graded index fibers can be further divided into single mode and multimode types. As the name indicates, a single mode fiber supports only one mode of propagation, where as multimode fibers contain many hundreds of modes. A few typical sizes of single and multimode fibers are shown in Fig.1.2. to provide an idea of the dimensional scale. Multimode fibers offer several advantages compared with single mode fibers. The greater core radii of multimode fibers shape it easier to launch optical power into the fiber and ease the connecting together of similar fibers. Other benifit is that optical wave can be launched into a multimode fiber using a LED source, where as mono mode fibers must normally be excited with laser diodes. Although LED's have low optical output energy than laser diodes they are easier to make, are less costly, require less complex circuitry, and have higher life times than laser diodes, thus making them more desirable in certain applications in the optical fiber communication system.

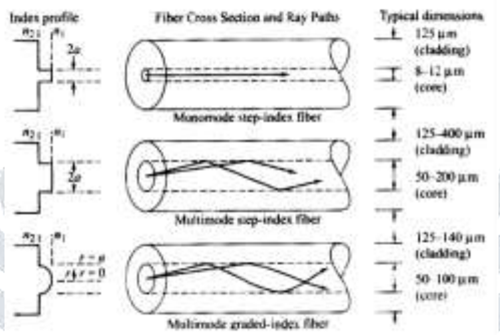


**Fig. 2** : Study of single mode fiber

A demerit of multimode fibers is that they face intermodal dispersion. When an optical wave is launched into a fiber, the optical power in the wave is distributed over all of the modes of the fiber. Each of the modes that can propagates in a multimode fiber travels at a slightly different velocity. This means that the modes in a given optical wave arrive at the fiber end at slightly different times, thus causing the wave to spread out in time as it travels along the fiber. This effect, which is known as inter modal dispersion or inter modal distortion, can be reduced by using a graded index profile in a fiber core. This permits graded-index fibers to have more larger frequency range (data rate communication abilities) than step index fibers. Even higher bandwidths are possible in single mode fibers where inter modal dispersion affects are not present.

Since a single mode optical fiber is an optical fiber which carries only a single ray of light or single mode of light wave, the ray of light may contain different wavelengths. In this fiber light waves travel parallel to the axis of the fiber, it is also called transverse mode (TM) because the electromagnetic vibrations occur in the perpendicular direction to the axis of the fiber. Single mode optical fibers do not exhibit modal dispersion resulting from multiple spatial modes.

Single mode fibers are therefore better at retaining the fidelity/quality of each light pulse over long distances than are multimode fibers. For these reasons single mode optical fiber have higher bandwidth.

There are several numbers of special types of single mode optical fiber which have been changed physically to give special properties such as dispersion shifted fiber and non-zero dispersion shifted fiber. The mode formation depends on the wavelength of the light used, so that this fiber mainly carry a small numbers of extra modes at visible wavelengths. The lowest order confined mode is ascertained for the frequency range of our interest by taking into account Maxwell's equations for the boundary conditions imposed by the fiber which can be calculated by the core diameter and the refractive indices of the core and cladding.

**Result & Discussion :-** In the single mode fiber the core and cladding having diameter (8 μm to 12 μm) and 125 μm are distributed as shown in F.g. 2

Single mode optical fiber has a very small core of glass having refractive index $n_1$ = 1.5. The outside cladding is air having refractive index $n_1$ = 1 when optical wave propagates in the cable it takes only one path as shown in fig. 2.

The value of critical angle for glass air interface used in this fiber is

$$\theta_c = Sin^{-1}\frac{n_2}{n_1} = Sin^{-1}\left(\frac{1}{1.5}\right) = 41.8$$

The acceptance angle

$$\theta_a = 90^0 - \theta_c = 90^0 - 41.8 = 48.2$$

This shows that this fiber accepts light from wide aperture, so it is easy to couple light from source into the cable. This type of fiber is very weak in working and hence has limited practical use. Some different type of fiber has cladding other than air having retractive index 1.48 then the value of critical angle for glass material interface is

$$\theta_c = Sin^{-1}\left(\frac{1.48}{1.5}\right) = 76.7^0 \approx 77^0$$

Acceptance angle

$$\theta_a = 90^0 - \theta_c = 90^0 - 77^0 \approx 13^0$$

This fiber accepts light from a very narrow aperture, hence it is difficult to couple light into the cable. In single mode fiber light is propagated through reflection. The light rays enter the fiber propagates straight down the core or totally internally reflected only once. It means all light rays follow the same path and take same time to travel the length of the cable.

Multimode fibers have large core diameter (50-200) μm and cladding diameter is of the order of (125-400) μm as shown in fig. 2.

They are of two types

(i) Multimode step index fiber

(ii) Multimode graded index fiber

In a multimode step index fiber, rays of light are guided along the fiber core by total internal reflection. This type of fiber has large light to fiber aperture and hence allows more light to enter the cable. If the angle of incidence on fiber cladding interface is less than critical angle, it will be lost. The critical angle is determined by the difference in index of refraction between the core and cladding materials. A high numerical aperture permits light to communicate down the fiber in rays both close to the axis and at various angles, permitting well organised coupling of light into the fiber. But high numerical aperture increases the amount of scattering because rays are at different angles cover different path lengths and therefore take different times to travel the fiber. So a low numerical aperture may be desirable. In this fiber core has uniform refractive index $n_1 \approx 1.48$ and the cladding has constant refractive index $n_2 = 1.46$ such as $n_2 < n_1$. This size of fiber is denoted as core diameter / cladding diameter both in μm such as 50/125, 200/400.

Since this fiber has large fiber aperture so it allows more light enter into the cable. Propagation of a light wave having three different wavelength component let them as $\lambda_1$, $\lambda_2$, $\lambda_3$ are shown in figure 3. Let as assume that the light wave having wavelength $\lambda_1$ meets the core cladding boundary at critical angle and waves having wavelength $\lambda_2$ and $\lambda_3$ incident at an angle slightly greater than the critical angle. All the light waves suffer a multiple reflection inside the fiber. Since they have different paths so they reach the other end at different times so the information signal is distorted.

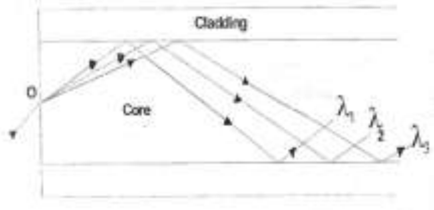


**Fig. 3** Propagation of optical wave through multimode step index fiber consisting three components $\lambda_1$, $\lambda_2$, $\lambda_3$

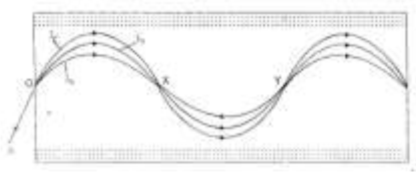


**Fig. 4** Propagation of optical wave through multimode graded index fiber consisting three components $\lambda_1$, $\lambda_2$, $\lambda_3$

In Graded index multimode fiber the central core is of non uniform refractive index which as maximum value at the centre and decreases gradually with distance towards the outer edge in a nearly parabolic manner. In it the refractive index in the core decreases continuously in a nearly parabolic manner from a maximum value at the centre of the core to a constant value at the core cladding boundary. This type of fiber transmit signal effectively. Proportions in μm are demonstrated like as 100/140 and 50/125. In Graded-index multimode fiber (Fig. 4) paths are different but all come to focus at the same time at X and then at Y. This is possible because the speed is inversely proportional to refractive index and so wavelength $\lambda_1$ travels a longer path than $\lambda_2$ or $\lambda_3$ but in the region of lesser n time of travel is same whichever is path. Thus all wavelengths arrive at the other end of the fiber at the same time.

**Conclusion** :- Single mode optical fibers do not exhibit modal dispersion resulting from multiple spatial modes. Single mode fibers are therefore better at retaining the fidelity/quality of each light pulse over long distances than are multimode fibers. For these reasons single mode optical fiber has higher bandwidth. We have concluded that single mode fibers are the best choice when distance of communication is very large and also the bandwidth requirement is the primary concern (for example in long distance high- speed communication like WAN etc.). It has the best dispersion performance out of the three.

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