Scientific Journal of Impact Factor (SJIF): 4.72

e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 8, August -2017

A comparative study of fiber type (refractive index profile)

Dinesh Kumar[1] & Dr. (Mrs.) Taran Kumari[2] Dr. Mahesh Pd. Roy[3]

[1]*Research Scholar, University Department of Physics, B.R.A.Bihar University,Muzaffarpur, Bihar, India .*
[2]*Associate Professor, University Department of Physics, B.R.A.Bihar University, Muzaffarpur ,Bihar,India.*
[3] *Retired Science Teacher, D.N.S.H. Muzaffarpur*

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

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

Introduction:- 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 axis of the optical fiber waveguide. The main components of the optical fiber system are the optical fiber 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, materials used for fibers, loss mechanism in fiber and degree of dispersion of signal as it travels along the fiber. An optical fiber is a dielectric wave guide that operates 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 transmission properties of an optical wave guide are dictated by its configuration characteristics which have a major effect in determining how an optical signal is affected as it propagates along a fiber. In this paper we have studied fiber type based on refractive index profile.

Proposed work:- Among many different configurations of the optical waveguide, the most widely accepted configuration is the single solid dielectric cylinder of radius a and index of refraction n_1 shown in Fig, 1. This cylinder is known 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 scattering loss that results from dielectric discontinuities at the core surface, it adds mechanical strength to the fiber and it protects 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. Higher–loss plastic – core fibers with plastic claddings are also widely in use. In addition, most fibers are encapsulated 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 gives rise to the three 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**.

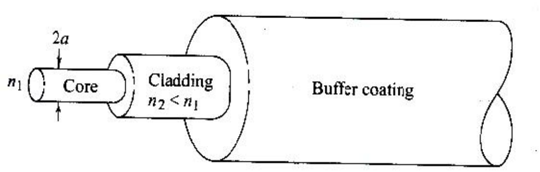


Fig. 1: Schematic of a conventional silica fiber structure. A circular solid core of refractive index n_1 is surrounded by a cladding having a refractive index n_2 less than n_1. An elastic plastic buffer encapsulates the fiber.

Both the step and graded index fibers can be further divided into single mode and multimode types. As the name implies, a single mode fiber sustains 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.2. to provide an idea of the dimensional scale. Multimode fibers also offer some advantages compared with single mode fibers. The larger core radii of multimode fibers make it easier to launch optical power into the fiber and facilitate the connecting together of similar fibers. Another advantage is that optical wave can be launched into a multimode fiber using a light- emitting–diode (LED) source, where as single mode fibers must generally be excited with laser diodes. Although LED's have less optical output power than laser diodes they are easier to make, are less expensive, require less complex circuitry, and have longer life times than laser diodes, thus making them more desirable in certain applications especially short distance in the optical fiber communication system. In this paper we have described the fiber type which suitable for long distance communication system.

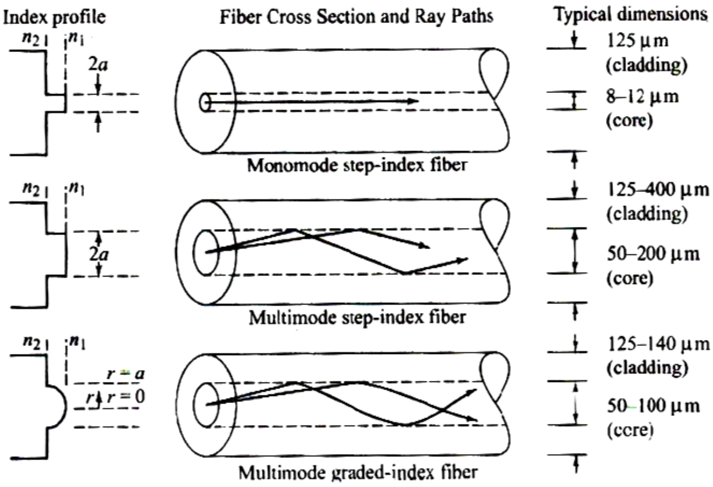


Fig. 2 : **A comparative study of fiber type (refractive index profile)**

A disadvantage of multimode fibers is that they suffer from 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 allows graded-index fibers to have much larger bandwidths (data rate transmission capabilities) 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 has 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 structure depends on the wavelength of the light used, so that this fiber actually supports a small numbers of additional modes at visible wavelengths. The lowest order bound mode is ascertained for the wavelengths of interest by solving Maxwell's equations for the boundary conditions imposed by the fiber which can be determined by the core diameter and the refractive indices of the core and cladding. The solution of Maxwell's equation for the lowest order bound mode will permit a pair of orthogonally polarized fields in the fiber.

Result and 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 allows light to propagate down the fiber in rays both close to the axis and at various angles, allowing efficient coupling of light into the fiber. But high numerical aperture increases the amount of dispersion because rays are at different angles have different path lengths and therefore take different times to traverse 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 λ_1, λ_2, λ_3 are shown in figure 3. Let as assume that the light wave having wavelength λ_1 meets the core cladding boundary at critical angle and waves having wavelength λ_2 and λ_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.

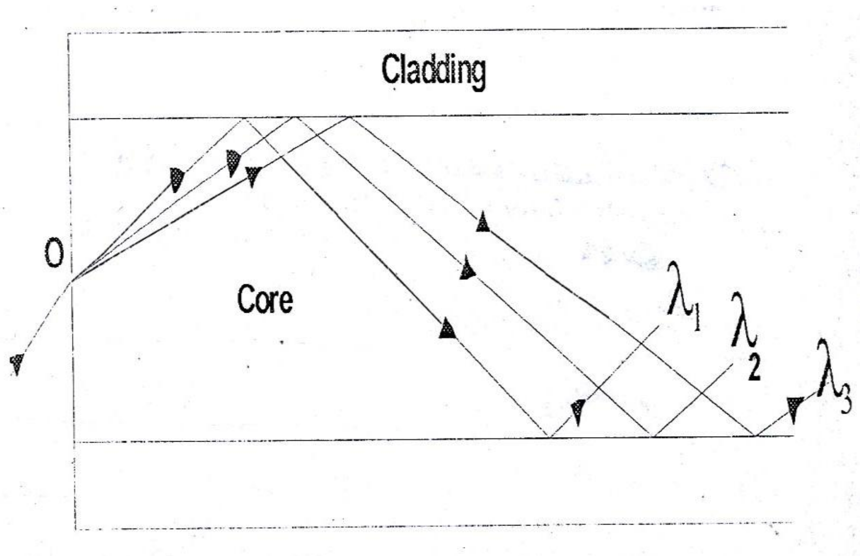


Fig. 3 Propagation of optical wave through multimode step index fiber consisting three components λ_1, λ_2, λ_3

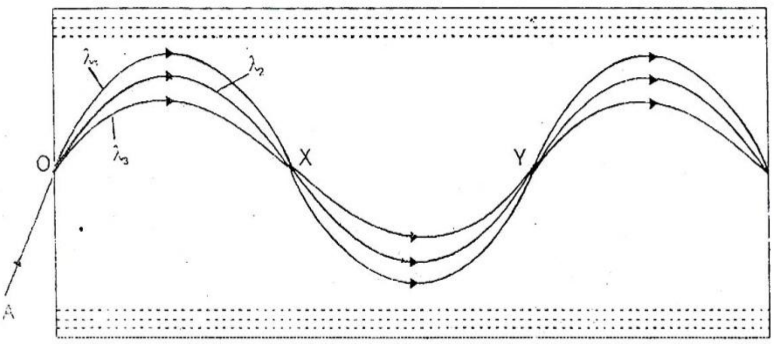


Fig. 4 Propagation of optical wave through multimode graded index fiber consisting three components λ_1, λ_2, λ_3

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. Size in μm are denoted such as 50/125 and 100/140. 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 λ_1 travels a longer path than λ_2 or λ_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.

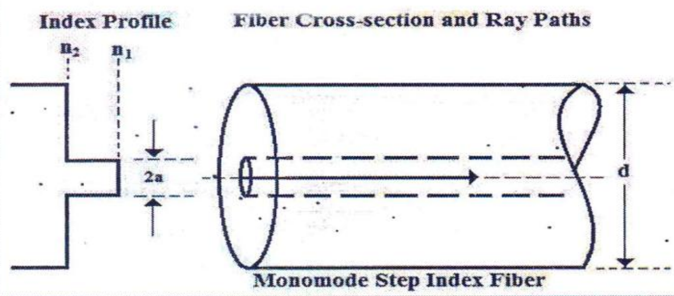
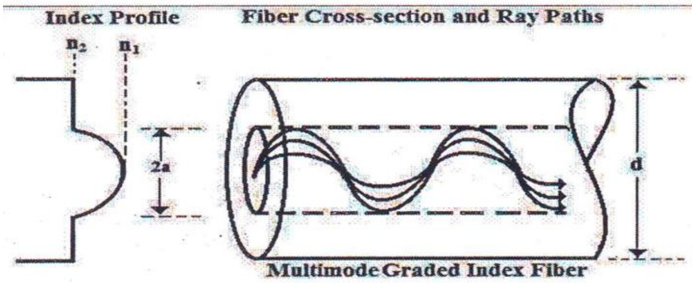
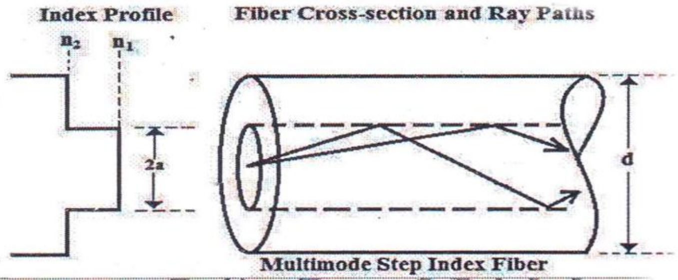
Index Profile and Cross sectional view of different types of fibers	Core Diameter (2a) (μm)	Cladding Diameter (d)(μm)	Bandwidth
 Index Profile; Fiber Cross-section and Ray Paths; n_2 n_1 2a d; Monomode Step Index Fiber	8-12	125	High
 Index Profile; Fiber Cross-section and Ray Paths; n_2 n_1 2a d; Multimode Graded Index Fiber	50-100	125-140	Fare
 Index Profile; Fiber Cross-section and Ray Paths; n_2 n_1 2a d; Multimode Step Index Fiber	50-200	125-400	Lowest

Table 1 : Comparative study of fiber type(refractive index profile)

From the above table it can be very well 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 and hence the higher bandwidth out of the three. In the multimode graded index optical fiber, which has N.A. higher than single mode fiber but its dispersion performance is about 10 times poorer than that of a single mode fiber. Applications where the distance of communication is short and the designer does not want to sacrifice much on the light gathering efficiency, this types of optical fiber appropriately serve the purpose (for example in local area communications like LANs, Intranet etc.) Multimode step index fibers are left with only academic importance and for use in laboratory demonstrations because though they have high N.A, their dispersion performance to poor to be of any use in communication. They may be used in optical sensor for their high N.A, but have very limited range of application.

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.

Further work: The simplest model of light, "The ray-Model" helped us to understand the propagation of light inside the optical fiber core in detailed manner in optical fiber. The ray-model has been successful in explaining many issues about light propagation in an optical fiber, but they are not all. There are other concepts those which the ray-model fails to explain. One such concept is the dependence of the propagation characteristics of light on the wavelength. The ray-model suggest that all wavelength travel with same characteristics. But it is not show. Thus we have to think the next higher model of light "The wave model". In this model, optical wave is treated as an electromagnetic wave. For further discussions we think about electromagnetic wave theory and the propagation of em waves in a bound medium.

References:
1. Optical fiber communications, fourth edition, Mc. Graw- Hill, Gerd Keiser.
2. Lecture 4, model propagation of light in an optical fiber, Prof. R.K. shevgaonkar, Deptt of electrical engineering, IIT. Bombay.s