

# Applications of Optical Fiber

<sup>1</sup>Dr. K.Soundara Rajan, <sup>2</sup>Md.Mujahid Basha, <sup>3</sup>Shaik.Rasool, <sup>4</sup>K.Vikram

<sup>1,2,3,4</sup>TKR Engineering College, Hyderabad, India

## Abstract

An optical fiber (or optical fibre) is a flexible, transparent fiber made by drawing glass (silica) or plastic to a diameter slightly thicker than that of a human hair. Optical fibers are used most often as a means to transmit light between the two ends of the fiber and find wide usage in fiber-optic communications, where they permit transmission over longer distances and at higher bandwidths (data rates) than wire cables. Fibers are used instead of metal wires because signals travel along them with lesser amounts of loss; in addition, fibers are also immune to electromagnetic interference, a problem from which metal wires suffer excessively. Fibers are also used for illumination, and are wrapped in bundles so that they may be used to carry images, thus allowing viewing in confined spaces, as in the case of a fiberscope. Specially designed fibers are also used for a variety of other applications, some of them being fiber optic sensors and fiber lasers.

## Keywords

Multi Mode Fiber, Single Mode Fiber, Copper Wiring

## I. Introduction

An important aspect of a fiber optic communication is that of extension of the fiber optic cables such that the losses brought about by joining two different cables is kept to a minimum [7]. Joining lengths of optical fiber often proves to be more complex than joining electrical wire or cable and involves careful cleaving of the fibers, perfect alignment of the fiber cores, and the splicing of these aligned fiber cores. For applications that demand a permanent connection a mechanical which holds the ends of the fibers together mechanically could be used or a fusion splice that uses heat to fuse the ends of the fibers together could be used. Temporary or semi-permanent connections are made by means of specialized optical fiber connectors.

## II. Advantages Over Copper Wiring

Broad bandwidth Immunity to electromagnetic interference  
Electrical insulator Material cost and theft prevention Security of information passed down the cable Sensors

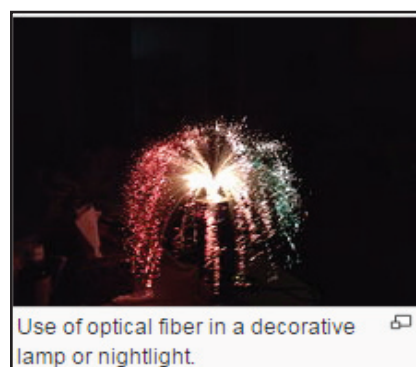
Fibers have many uses in remote sensing. In some applications, the sensor is itself an optical fiber. In other cases, fiber is used to connect a non-fiber optic sensor to a measurement system. Depending on the application, fiber may be used because of its small size, or the fact that no electrical power is needed at the remote location, or because many sensors can be multiplexed along the length of a fiber by using different wavelengths of light for each sensor, or by sensing the time delay as light passes along the fiber through each sensor. Time delay can be determined using a device such as an optical domain.

Sensors that vary the intensity of light are the simplest, since only a simple source and detector are required. A particularly useful feature of such fiber optic sensors is that they can, if required, provide distributed sensing over distances of up to one meter. In contrast, highly localized measurements can be provided by integrating miniaturized sensing elements with the tip of the fiber [40]. These can be implemented by various micro- and nanofabrication technologies, such that they do not exceed the microscopic boundary of the fiber tip, allowing such applications

as insertion into blood vessels via hypodermic needle. Extrinsic fiber optic sensors use an optical fiber cable, normally a multi-mode one, to transmit modulated light from either a non-fiber optical sensor—or an electronic sensor connected to an optical transmitter. A major benefit of extrinsic sensors is their ability to reach otherwise inaccessible places. An example is the measurement of temperature inside aircraft jet engines by using a fiber to transmit radiation into a radiation pyrometer outside the engine. Extrinsic sensors can be used in the same way to measure the internal temperature of electrical transformers, where the extreme electromagnetic fields present make other measurement techniques impossible. Extrinsic sensors measure vibration, rotation, displacement, velocity, acceleration, torque, and twisting.



Light reflected from optical fiber illuminates exhibited model



Use of optical fiber in a decorative lamp or nightlight.

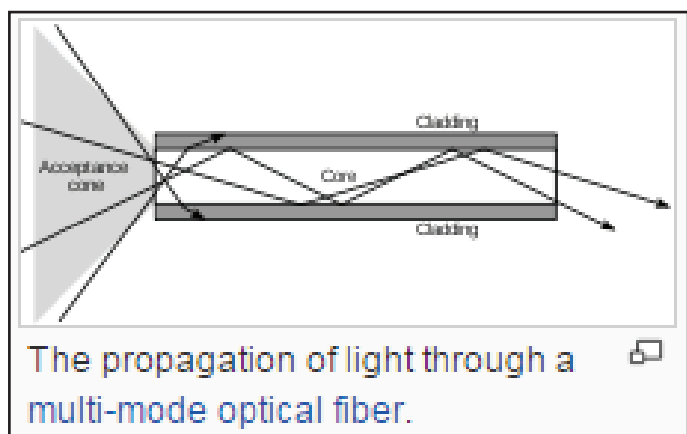


A frisbee illuminated by fiber optics

Optical fibers have a wide number of applications. They are used as light guides in medical and other applications where bright light needs to be shone on a target without a clear line-of-sight path. In some buildings, optical fibers route sunlight from the roof to other parts of the building. Optical fiber is also used in imaging optics. A coherent bundle of fibers is used, sometimes along with lenses, for a long, thin imaging device called an endoscope, which is used to view objects through a small hole. Medical endoscopes are used for minimally invasive exploratory or surgical procedures. Industrial endoscopes Optical fiber is also widely exploited as a nonlinear medium. The glass medium supports a host of nonlinear optical interactions, and the long interaction lengths possible in fiber facilitate a variety of phenomena, which are harnessed for applications and fundamental investigation [47]. Conversely, fiber nonlinearity can have deleterious effects on optical signals, and measures are often required to minimize such unwanted effects.

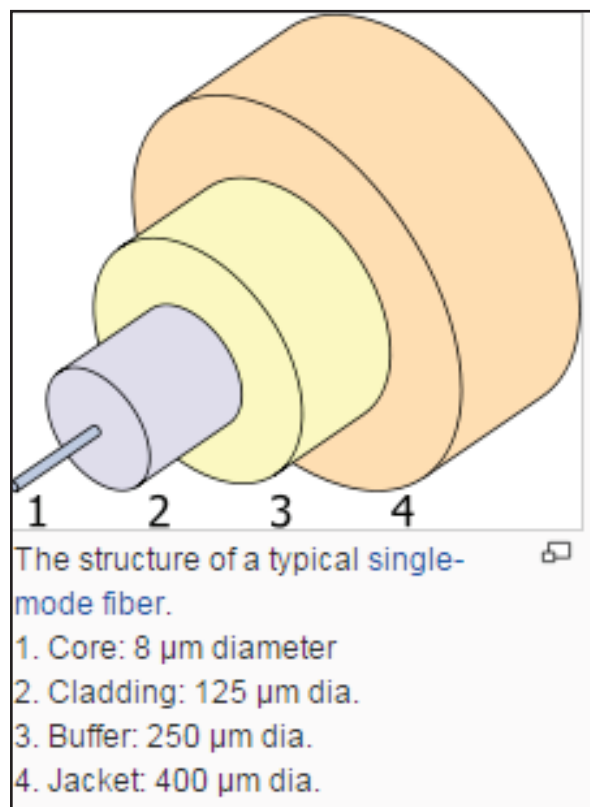
**A. Multi-mode Fiber**

Fiber with large core diameter (greater than 10 micrometers) may be analyzed geometrical. Such fiber is called multi-mode fiber, from the electromagnetic analysis (see below). In a step-index multi-mode fiber, rays of light are guided along the fiber core by total internal reflection. Rays that meet the core-cladding boundary at a high angle (measured relative to a line normal to the boundary), greater than the critical angle for this boundary, are completely reflected. The critical angle (minimum angle for total internal reflection) is determined by the difference in index of refraction between the core and cladding materials. Rays that meet the boundary at a low angle are refracted from the core into the cladding, and do not convey light and hence information along the fiber. The critical angle determines the acceptance angle of the fiber, often reported as a numerical aperture. 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. However, this high numerical aperture increases the amount of dispersion as rays at different angles have different path lengths and therefore take different times to traverse the fiber. In graded-index fiber, the index of refraction in the core decreases continuously between the axis and the cladding. This causes light rays to bend smoothly as they approach the cladding, rather than reflecting abruptly from the core-cladding boundary. The resulting curved paths reduce multi-path dispersion because high angle rays pass more through the lower-index periphery of the core, rather than the high-index center. The index profile is chosen to minimize the difference in axial propagation speeds of the various rays in the fiber. This ideal index profile is very close to a parabolic relationship between the index and the distance from the axis.



**B. Single Mode Fiber**

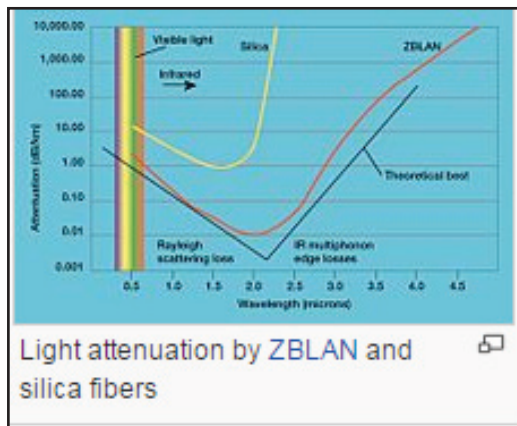
Fiber with a core diameter less than about ten times the wavelength of the propagating light cannot be modeled using geometric optics. Instead, it must be analyzed as an electromagnetic structure, by solution of Maxwell’s equations as reduced to the electromagnetic wave equation. The electromagnetic analysis may also be required to understand behaviors such as speckle that occur when coherent light propagates in multi-mode fiber. As an optical waveguide, the fiber supports one or more confined transverse modes by which light can propagate along the fiber. Fiber supporting only one mode is called single-mode or mono-mode fiber. The behavior of larger-core multi-mode fiber can also be modeled using the wave equation, which shows that such fiber supports more than one mode of propagation (hence the name). The results of such modeling of multi-mode fiber approximately agree with the predictions of geometric optics, if the fiber core is large enough to support more than a few modes.



**C. Mechanism for Attention**

Attenuation in fiber optics, also known as transmission loss, is the reduction in intensity of the light beam (or signal) as it travels through the transmission medium. Attenuation coefficients in fiber optics usually use units of dB/km through the medium due to the relatively high quality of transparency of modern optical transmission media. The medium is usually a fiber of silica glass that confines the incident light beam to the inside. Attenuation is an important factor limiting the transmission of a digital signal across large distances. Thus, much research has gone into both limiting the attenuation and maximizing the amplification of the optical signal. Empirical research has shown that attenuation in optical fiber is caused primarily by both scattering and absorption. Single-mode optical fibers can be made with extremely low loss. Corning’s SMF-28 fiber, a standard single-mode fiber for telecommunications wavelengths, has a loss of 0.17 dB/km at 1550 nm.[49] For example, an 8 km length of SMF-28 transmits nearly 75% of light at 1,550 nm. It has been noted that if ocean

water was as clear as fiber, one could see all the way to the bottom even of the Marianas Trench in the Pacific Ocean, a depth of 36,000 feet



## Practical Issues

### III. Cable construction

In practical fibers, the cladding is usually coated with a tough resin coating and an additional buffer layer, which may be further surrounded by a jacket layer, usually plastic. These layers add strength to the fiber but do not contribute to its optical wave guide properties. Rigid fiber assemblies sometimes put light-absorbing (“dark”) glass between the fibers, to prevent light that leaks out of one fiber from entering another. This reduces cross-talk between the fibers, or reduces flare in fiber bundle imaging applications. Modern cables come in a wide variety of sheathings and armor, designed for applications such as direct burial in trenches, high voltage isolation, dual use as power lines, installation in conduit, lashing to aerial telephone poles, submarine installation, and insertion in paved streets. Multi-fiber cable usually uses colored coatings and/or buffers to identify each strand. The cost of small fiber-count pole-mounted cables has greatly decreased due to the high demand for fiber to the home (FTTH) installations in Japan and South Korea. Fiber cable can be very flexible, but traditional fiber’s loss increases greatly if the fiber is bent with a radius smaller than around 30 mm. This creates a problem when the cable is bent around corners or wound around a spool, making FTTH installations more complicated. “Bendable fibers”, targeted towards easier installation in home environments, have been standardized as ITU-T G.657. This type of fiber can be bent with a radius as low as 7.5 mm without adverse impact. Even more bendable fibers have been developed [72]. Bendable fiber may also be resistant to fiber hacking, in which the signal in a fiber is surreptitiously monitored by bending the fiber and detecting the leakage [73].

Another important feature of cable is cable’s ability to withstand horizontally applied force. It is technically called max tensile strength defining how much force can be applied to the cable during the installation period.

Some fiber optic cable versions are reinforced with aramid yarns or glass yarns as intermediary strength member. In commercial terms, usage of the glass yarns are more cost effective while no loss in mechanical durability of the cable. Glass yarns also protect the cable core against rodents and termites.

### IV. Termination and Splicing

Optical fibers are connected to terminal equipment by optical fiber connector. These connectors are usually of a standard type

such as FC, SC, ST, LC, MTRJ, or SMA. Optical fibers may be connected to each other by connectors or by splicing, that is, joining two fibers together to form a continuous optical waveguide. The generally accepted splicing method is arc , which melts the fiber ends together with an electric arc. For quicker fastening jobs, a “mechanical splice” is used.

Fusion splicing is done with a specialized instrument. The fiber ends are first stripped of their protective polymer coating (as well as the more sturdy outer jacket, if present). The ends are cleaved (cut) with a precision cleaver to make them perpendicular, and are placed into special holders in the fusion splicer. The splice is usually inspected via a magnified viewing screen to check the cleaves before and after the splice. The splicer uses small motors to align the end faces together, and emits a small spark between electrodes at the gap to burn off dust and moisture. Then the splicer generates a larger spark that raises the temperature above the meeting point of the glass, fusing the ends together permanently. The location and energy of the spark is carefully controlled so that the molten core and cladding do not mix, and this minimizes optical loss. A splice loss estimate is measured by the splicer, by directing light through the cladding on one side and measuring the light leaking from the cladding on the other side. A splice loss under 0.1 dB is typical. The complexity of this process makes fiber splicing much more difficult than splicing copper wire.



## V. Conclusion

The refractive index of fibers varies slightly with the frequency of light, and light sources are not perfectly monochromatic. Modulation of the light source to transmit a signal also slightly widens the frequency band of the transmitted light. This has the effect that, over long distances and at high modulation speeds, the different frequencies of light can take different times to arrive at the receiver, ultimately making the signal impossible to discern, and requiring extra repeaters.[78] This problem can be overcome in a number of ways, including the use of a relatively short length of fiber that has the opposite refractive index gradient.

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Dr. K. SounadaraRajan Working as a Professor and Director of R & D. in TKREC, Hyderabad. He receive B.E From S.V University, M.Tech From JNTUH, Ph.D. From IIT Roorkee. His area specialization is Microcomputers Electronic Instrumentation, Computer Operating Systems Image Processing, Lower power VLSI Technology. He Published Many Technical papers National and International

Level. Best Principal Best Principal Award by International Institute of Education and Management, New Delhi in 2011. Best Teacher Award by Lead India -2020 in 2005



Mr. Md. Mujahid basha has been working as a Asst. Professor in TKREC in dept. of Science. He is having experience 08. And published many papers.



Shaik Rasool has been working as a Asst. professor. in TKR Engineering , Hyderabad. He receive M.Sc. Degree from Andhra University and pursuing Ph.D from Acharya Nagarjuna University. He published many papers in various journals. He having good command in Physics.



Mr. K. Vikram is working as a Professor in TKR Engineering College, Hyderabad, India. He has published and presented good number of Technical papers in National and International Conferences. His main research interest areas are Software Engineering, Data Mining, and Networks. Image Processing He Worked as a I/C Principal in in various

Engineering colleges. He is life member of IETE, CSI. He published 30 International Papers and 05 International Conferences and published 03 Text Books.