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Transformation of Fiber Optic Communication Systems

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Abstract: This paper presents an overview of the latest research and development in the field of fiber optic communication systems, along with their technological trend towards the upcoming generation. Fiber optic communication system is a highly recommended medium for transmission of data over longer distances which ranges from gigabytes to terabytes. Wide-bandwidth signal transmission with minimal latency is a major requirement in present applications and that can be achieved by the usage of fiber optics communication system which results in higher bit rates and negligible latency. Transmission of information over fiber optics can be achieved by using a light wave technology, which converts electrical signals into light waves. Further, fiber optics has some incredible features such as wide bandwidth, narrower diameter, compact size, low attenuation and high degree of reliability with longer distance signal transmission.

Keywords: Bandwidth, Fiber Optics, Attenuation, Latency, Refractive Index, Transmission and Telecommunication networks.

I. INTRODUCTION

Light plays a vital role in modern life, particularly in optoelectronics and optical fiber telecommunication, where it enables the transmission of data through devices like compact disc players, digital cameras, and telecommunication cables.[1][3] The usage of low-loss optical transmission fibers has been instrumental in the success of optical communications technology and the development of components for telecommunications applications. The commercial introduction of fiber optic amplifiers in the 1990s revolutionized optical fiber transmissions, allowing signals to travel longer distances without regeneration.

The performance of communication systems is limited by the signal-to-noise ratio of the received signal and available bandwidth, which is quantified by the concept of channel capacity in information theory. Projects are being carried out worldwide to utilize optical fibers for transmitting signals from atomic clocks or highly coherent optical carriers generated by the optical standard for the purpose of international clock comparison and dissemination of accurate time signals. The paper is organized into three sections: Evolution of Fiber Optics, Optical fiber and the types of Optical Fibers, and Conclusions and Discussion.

II. EVOLUTION OF FIBER OPTICS

Optical fiber was first developed in 1970 by Corning Glass Works and GaAs semiconductor lasers were used for transmitting light through the fiber optic cables. In 1975, the first-generation fiber optic communication system was developed with a bit rate of 45 Megabits/sec at a wavelength of 0.8 µm. Later in 1980's, the second generation of fiber optics was developed, which used InGaAsP semiconductor lasers for transmission of light and operated at a wavelength of 1.3 µm. By 1987, these fiber optic systems were operating at bit rates of up to 1.7 Gigabits/second on single mode fiber with 50Km repeater spacing.[1][2]

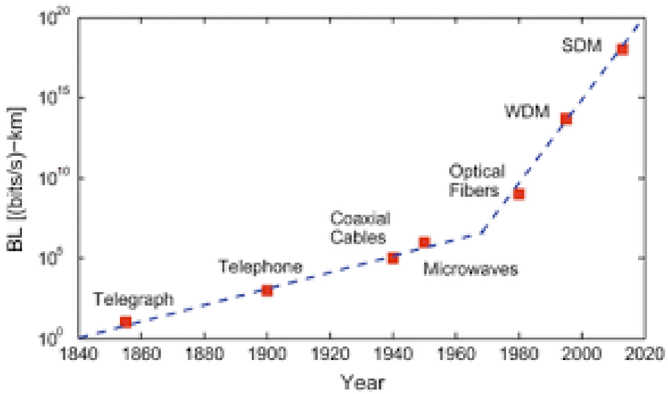

Fig 1. Evolution of Optical Fibers.

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The third generation of fiber optic communication system was developed in 1990 with a bit rate of up to 2.5 Gigabits/second on a single longitudinal mode fiber. However, the fourth generation of fiber optic systems used optical amplifiers as a replacement for repeaters and utilized the wavelength division multiplexing (WDM) in order to increase the data rates.[6][9]By 1996, transmission of over 11,300Km at a data rate of 5 Gigabits/second was demonstrated using submarine cables and eventually, the fifth generation of fiber optics involved Dense Wave Division Multiplexing (DWDM) to further increase the data rates up to 1Tbps. We can see the evolution of fiber optics as shown in Figure 1 above..

III. BASIC PRINCIPLE OF FIBER OPTICS

Optical Fiber is a communication system that works on the principle of Total Internal Reflection (TIR), where data in the form of light signal is transmitted over longer distances with minimal loss of energy. Generally, the cores of optical cables are thin fiber of glass or silicon with higher refractive index and covered by a layer of plastic called cladding. The optical frequency (2 x 1014 Hz) used in this form of communication has the ability to carry greater information and thus has a higher bandwidth. The benefits of employing a fiber optic communication system over electric cables are high level of signal security, absence of electromagnetic interference and difficulty in altering the data being conveyed.[3][5][8]

The main components of fiber optic communication systems are optical fiber, light signal transmitter, a photo-detecting receiver and other components such as connectors, optical amplifiers, regenerators, beam splitters etc.

IV. WORKING OF OPTICAL FIBER COMMUNICATION SYSTEM

The major components of an optical fiber communication system are optical transmitter, optical fiber and optical receiver as shown in Figure 2 below. Basically, a fiber optic system converts an electrical signal into a light signal which is transmitted through an optical fiber. At the receiver end of the optical fiber, it is converted back into an electric signal.

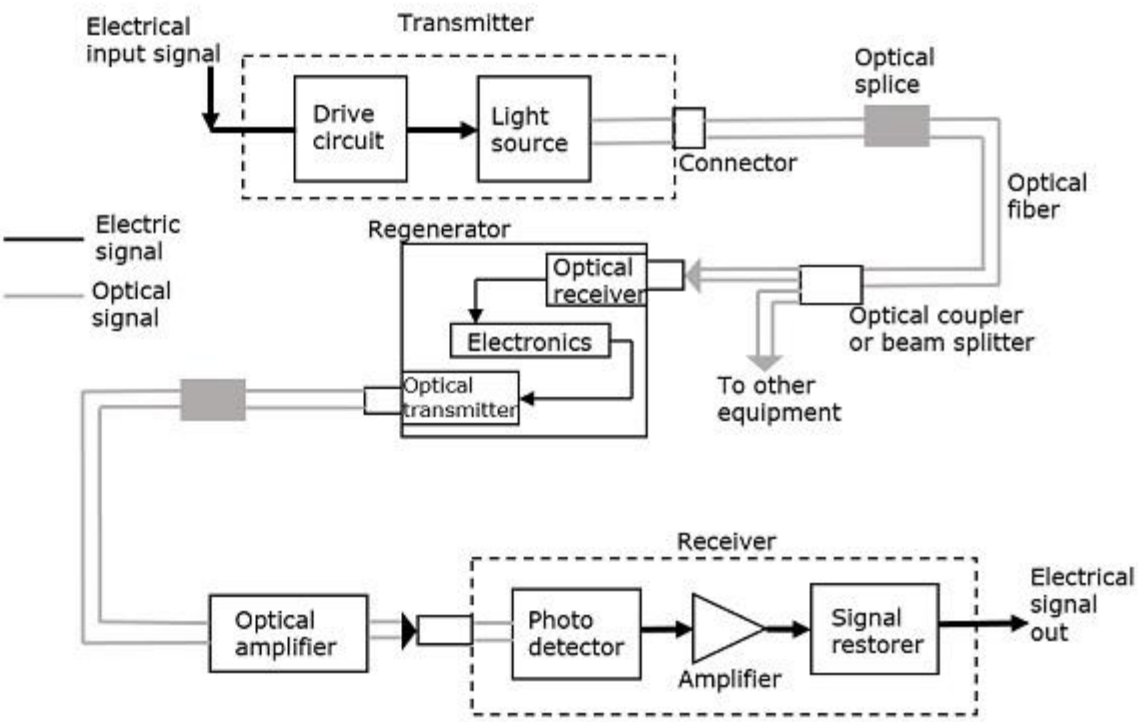

Fig 2. Block Diagram of Fiber Optic Communication System.

Encoder is an electrical circuit which will encode the given information into binary sequences of zeros and one. Each 'one' corresponds to an electrical pulse and 'zero' corresponds to an absence of a pulse in a light wave transmitter. The light source can be turned on and off based on the requirement with the help of these electrical pulses. The driver helps in converting the incoming electrical signal into a respective form compatible with the light source.

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The optical fiber here acts as a dielectric waveguide which helps in transmitting the optical pulses towards the receiver, which works on the principle of total internal reflection. The light detector receives the optical pulses and converts them back into electrical pulses, while these signals are amplified with the help of an amplifier and decoded by the decoder.

V. OPTICAL FIBERS

An optical fiber is a cylindrical dielectric waveguide which is made up of low-loss materials, that is often a fused silica glass of high chemical purity. A core of the waveguide has a higher refractive index than that of the outer medium called cladding, such that light is guided along the fiber axis by total internal reflection. Unlike the copper form of transmission, fiber optics is not electrical in nature and it can be used as a source of medium for carrying information in the form of light from one point to another.

We can categorize the optical fibers into various types depending on the refractive index, materials used and mode of propagation of light.

1. Classification based on Refractive Index

Optical Fibers can be classified into two types based on Refractive Index profile as shown below.

a. Step Index Fiber

Step index fiber is an optical waveguide, which has a constant refractive index within the core and cladding. The refractive index of the core is more when compared to that of cladding. However, the refractive index shows a sudden variation at the core-cladding interface and the index of refraction resembles a step-function when the graph is plotted as a function of distance from the center of fiber. When light rays propagate along the step index optical fiber it resembles a zigzag path and these patterns are totally composed of straight lines due to total internal reflection.[2]

b. Graded Index Fiber

Graded Index Fiber is a type of fiber where the refractive index of the core is non-uniform, which is present due to their higher refractive index at the axis of the core. The core in a graded-index fiber has an index of refraction that varies radially and decreases continuously in parabolic manner from maximum value at center of the core to constant value at cladding interface. As a result, the light travels faster at the edges of the core than in the center. However, the refractive index of the cladding is constant in the case of graded index fiber and hence the nature of refractive index is somewhat parabolic.[1][2] Figure 3 depicts the Cross Sectional View and Refractive Index Profile of Step Index and Graded Index Fiber.

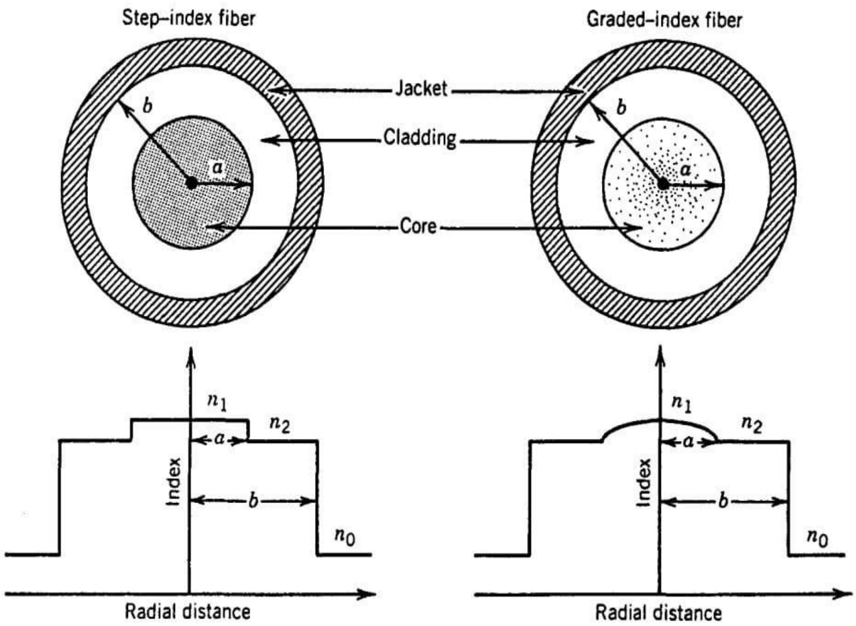

Fig 3. Cross Sectional View and Refractive Index Profile of Step Index and Graded Index Fiber.

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2. Classification based on Materials Used

Classification of Fibers based on Materials Used can be done in two-ways as shown below.

a. Plastic Fiber

Plastic fibers typically consist of a PMMA (acrylic) or polycarbonate core with a silicon resin cladding which comes with both benefits and drawbacks. It comes with a wide variety of diameters ranging from 0.15-2 mm and can go up to 20 mm. Some of the benefits of plastics fibers are Lower material cost, less manufacturing complexity along with flexibility and capability to withstand vibration and unsteady environments. However, it has some major drawbacks such as being unable to withstand harsh environments and can only transmit a narrow spectrum of visible light.[1][2]

b. Glass Fiber

Glass fibers typically consist of a pure glass core and include some of the major advantages such as adaptability to extreme temperatures, capability of handling wet and corrosive environments, minimal losses with larger numerical aperture to transmit a wide spectrum of rays. Some of the limitations are limited diameter size and more fragile with prone to breakage. Due to the presence of high transmissivity and low loss factor, glass fibers are ideal choices for long-distance and high-speed communication applications.[1][2][4] We can see the difference of materials used affecting the output in Figure 4 as shown below.

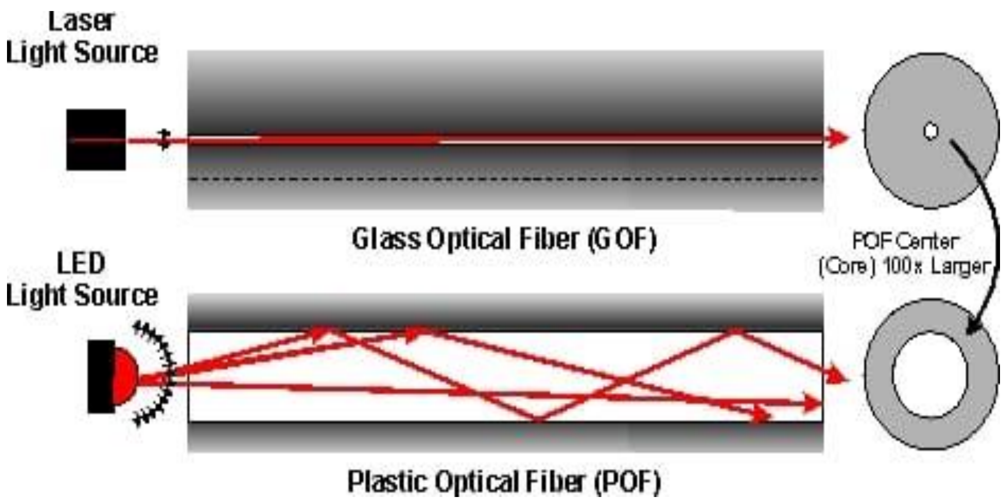

Fig 4. Classification based on Materials Used.

3. Classification based on Modes of Propagation

Classification of Fibers based on Modes of Propagation can be done in two-ways as shown below.

a. Single Mode Fiber

The single mode fibers are also known as step-index fibers, which are usually made up of doped silica. Due to the presence of a smaller diameter of the core (5-10µm), the single mode fibers can only allow one mode of propagation through them. But, the diameter of cladding is very large compared to that of core diameter which is generally around 125µm. As a result, there will be significant reduction in the optical loss of single mode fibers.[1][2]

b. Multimode Fiber

The multimode fibers are majorly used in the manufacture of both step index and graded index fibers. The multimode fibers are created from various components such as Glass, Silica, doped silica etc. In case of multimode fibers, the core diameter which ranges from 50-350µm is comparatively bigger than single mode fibers and inturn helps in allowing multiple modes of propagation through them.[1][2][4] We can see the difference of Modes of Propagation affecting the output in Figure 5 as shown below.

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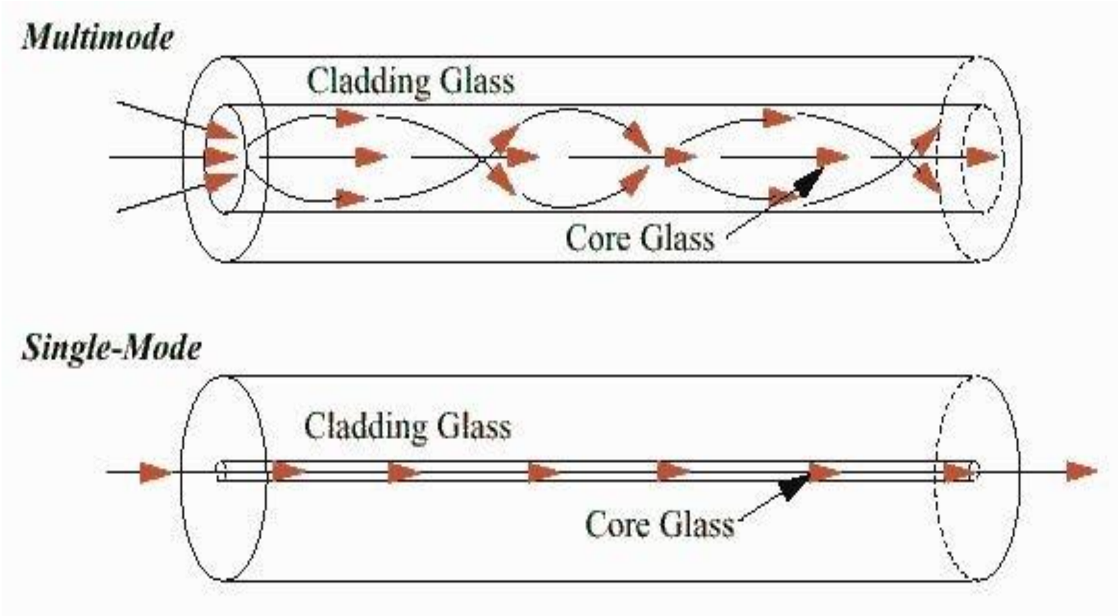

Fig 5. Classification based on Modes of Propagation.

4. Classification based on Refractive Index and Modes of Propagation

Classification of Fibers based on Refractive Index and Modes of Propagation can be done in three-ways as shown in Figure 6 below.

a. Step Index Single-Mode Fiber

In step index single mode fiber, the core diameter is extremely small and its size lies nearly between 2 to 15 micrometers. It allows only a single ray of light to propagate through the step index fiber and as a result, the transmitted ray does not experience any kind of distortion due to their delay in differences.[1]

b. Step Index Multimode Fiber

In step index multimode fiber, the diameter of the core is sufficiently large and the size of core lies nearly between 50 to 1000 micrometers. The multimode fiber allows a propagation of multiple light rays simultaneously through it and the fiber experiences distortion due to delay in their propagation time. In majority of the cases, light emitting diodes (LED) will be acting as a source of light.[1]

c. Graded Index Multimode Fiber

The graded-index multimode fiber has a diameter of core, which lies nearly between 50 to 100 micrometer and hence allows the multiple rays of light to propagate through the fiber. The refractive index of the core at the axis is comparatively larger when compared to that of other parts inside it. Thus when the light is propagated through fiber, it travels from less denser medium to more denser medium and we know the fact that light must travel from denser to rarer medium for TIR to take place. Hence, the light ray gets refracted despite being reflected inside the core. Thus in the case of graded-index multimode fiber, the light rays do not propagate through a straight line, rather they follow a parabolic path due to non-uniformity in the refractive index of the core.[1][2][3][5]

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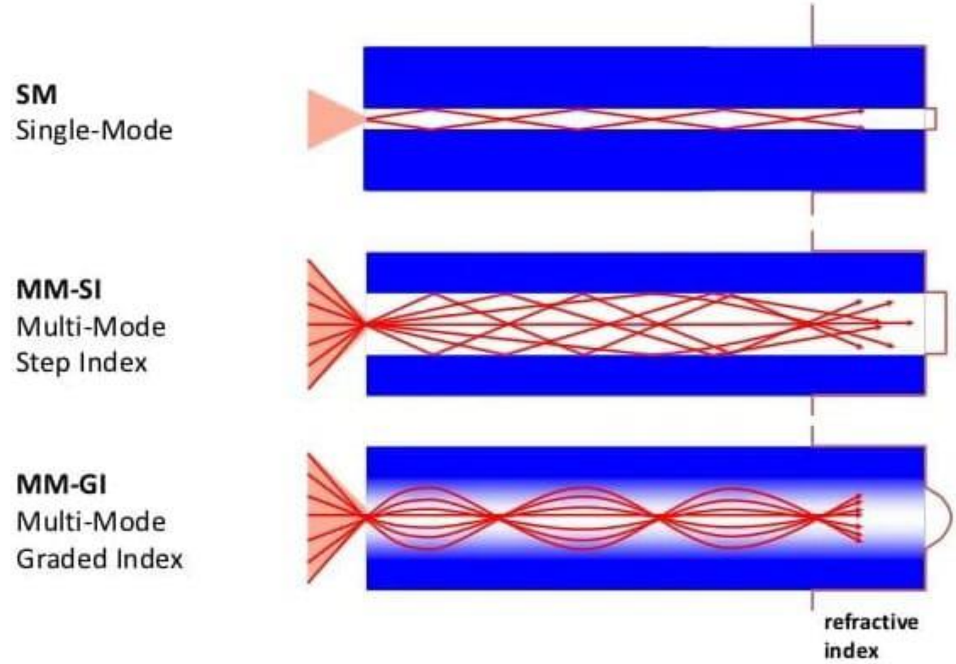

Fig 6. Classification based on Refractive Index and Modes of Propagation

VI. CONCLUSION

The main objective of this paper is to review the latest research and development in the field of fiber optic communication. Optical fiber technology has been used in many areas of tele- communication, photonics, medical and engineering. Its performance, low loss, freedom from interference, higher bandwidth and inherently high data transmission capacity have attracted many researchers. Optical fiber is an important component of communication infrastructure and its higher bandwidth capability with low attenuation characteristics has made it ideal for gigabit transmission and above. Various fiber types with their applications, light sources and detectors, couplers, splitters and wavelength division multiplexers (WDM) used in modern high-bandwidth communication systems have been introduced. Although fiber optics have many advantages, fiber optic technology still has some drawbacks. One among such drawbacks is that optical fibers are more expensive than copper cables, despite the fact of materials being naturally abundant.

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