Optical Fiber

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Abstract- **Introductions to optical fiber explaining what are they and their advantages over cooper wire. Also how the index of reflection and total internal reflection effect their operation. Also we will see the applications of fiber optics in communications and sensors.**

I. Introduction

An optical fiber is a glass or plastic fiber that sends light along its length. Fiber optics is the overlap of applied science and engineering concerned with the design and application of optical fibers.

Light is kept in the optical fiber by total internal reflection. This causes the fiber to act as a waveguide. The fibers that support many propagation paths are called multi-mode fibers (MMF). Fibers which can only support a single mode are called single-mode fibers (SMF). Multi-mode fibers have a larger core diameter, and used for short-distance communication links and for applications where high power must be transmitted. Single-mode fibers are used for most communication links longer than 550 meters.

In the 1970s, the telecommunication industry invested in optical fiber research. Optical fiber provides an attractive alternative to wire transmission lines and it has advantages over copper in high bandwidth, low attenuation, noise susceptibility, secure communication and low cost.

II. Principle of Operation

An optical fiber is a cylindrical dielectric waveguide that sends light along its axis by internal reflection. The optical fiber consists of a core surrounding medium called the cladding. To restrict the signal in the core, the refractive index of the core must be larger than that of the cladding.

A. *Index of refraction*

The index of refraction is a way of measuring the speed of light in a material. In vacuum light travels the fastest, such as outer space. The speed of light in vacuum is 299,792 Km/s. The index of refraction is calculated by dividing the speed of light in a vacuum by the speed of light in the medium. The index of refraction of a vacuum is therefore 1, by definition. The typical value of the index of refraction for the cladding of fiber is 1.46. The core value is typically 1.48. As the index of refraction get larger, the more slowly light travels in that medium.

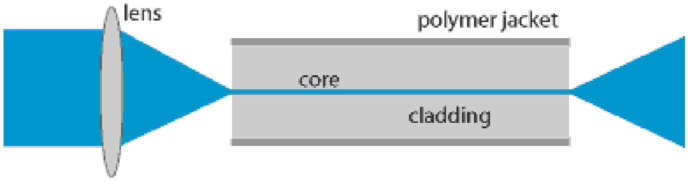

Figure 1: Simple setup for launching light into a glass fiber (not to scale). The light propagates along the core and leaves the other fiber end as a divergent beam. The fiber core and cladding are made of glass. A polymer jacket protects the fiber.

B. *Total internal reflection*

When light traveling in a medium hits a boundary at a steep angle the light will be completely reflected. This effect is used in optical fibers to restrict the light in the core. Light travels along the fiber bouncing back and forth of the boundary. Because the light must hit the boundary with an angle less than the critical angle of the fiber, only the signals that enter the fiber within a certain range of angles can travel down the fiber without leaking out. This range of angles is called the acceptance cone of the fiber. The size of this acceptance cone is a function of the refractive index difference between the fiber's core and cladding.

The sine of this maximum angle (the maximum angle from the fiber axis so that light may enter the fiber and propagate) is the numerical aperture (NA) of the fiber. Fiber with a larger NA requires less precision to splice and work with than fiber with a smaller NA.

$$NA = \sqrt{n_{core}^2 - n_{cladding}^2}$$

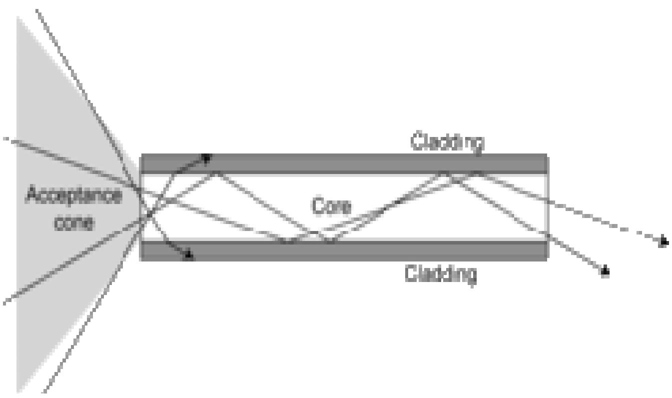

Figure 2: The propagation of light through an optical fiber.

C. Fiber Modes

A fiber can support one or several guided modes, the intensity distributions of which are located at or immediately around the fiber core, although some of the intensity may propagate within the fiber cladding. In addition, there is a multitude of cladding modes, which are not restricted to the core region. The optical power in cladding modes is usually lost after some moderate distance of propagation, but can in some cases propagate over longer distances. Outside the cladding, there is typically a protective polymer coating, which gives the fiber improved mechanical strength and protection against moisture, and also determines the losses for cladding modes. An important distinction is that between single-mode and multimode fibers.

Single Mode cable is a single stand of glass fiber with a diameter of 8.3 to 10 microns that has one mode of transmission. Single Mode Fiber with a relatively narrow diameter, through which only one mode will propagate typically 1310 or 1550nm. Carries higher bandwidth than multimode fiber, but requires a light source with a narrow spectral width. Single Mode fiber is used in many applications where data is sent at multi-frequency (WDM Wave-Division-Multiplexing) so only one cable is needed. Single-mode fiber gives you a higher transmission rate and up to 50 times more distance than multimode, but it also costs more. Single-mode fiber has a much smaller core than multimode. The small core and single light-wave virtually eliminate any distortion that could result from overlapping light pulses, providing the least signal attenuation and the highest transmission speeds of any fiber cable type. Efficiently launching light into a single-mode fiber usually requires a laser source with good beam quality and precise alignment of the focusing optics in order to achieve mode matching. The mode radius of a single-mode fiber is often of the order of 5 μm. Single-mode optical fiber is an optical fiber in which only the lowest order bound mode can propagate at the wavelength of interest typically 1300 to 1320nm.

Multi-Mode cable has a little bit bigger diameter, with a common diameters in the 50-to-100 micron range for the light carry component. Most applications in which Multi-mode fiber is used, 2 fibers are used (WDM is not normally used on multi-mode fiber). POF is a newer plastic-based cable which promises performance similar to glass cable on very short runs, but at a lower cost. Multimode fiber gives you high bandwidth at high speeds over medium distances. Light waves are dispersed into numerous paths, or modes, as they travel through the cable's core typically 850 or 1300nm. Typical multimode fiber core diameters are 50, 62.5, and 100 micrometers. However, in long cable runs (greater than 900 meters), multiple paths of light can cause signal distortion at the receiving end, resulting in an unclear and incomplete data transmission so designers now call for single mode fiber in new applications using Gigabit and beyond.

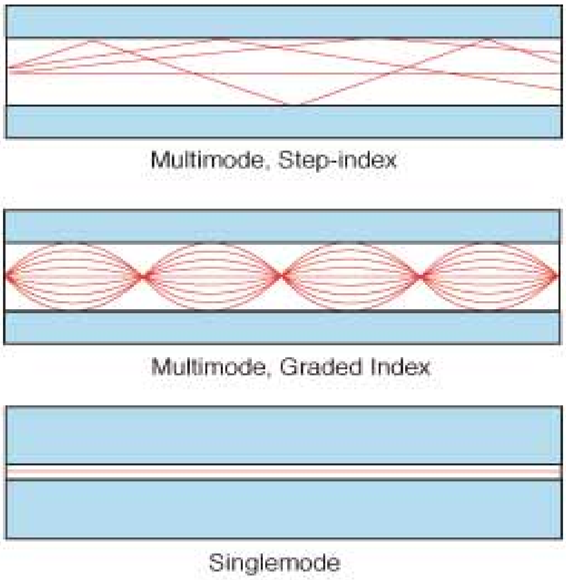

Figure 3: Optical fiber types.

III. APPLICATIONS

A. Optical fiber communication

Optical fiber is used for telecommunication and networking because it is flexible and can be bundled as cables. It is especially advantageous for long-distance communications, because light propagates through the fiber with little attenuation compared to electrical cables. Additionally, the per-channel light signals propagating in the fiber can be modulated at rates as high as 111 Gb/s, Each fiber can carry many independent channels, each using a different wavelength of light (wavelength-division multiplexing (WDM)).

Over short distances fiber saves space in cable ducts because a single fiber can carry much more data than a single electrical cable. Fiber is also immune to electrical and electromagnetic interference. Non-armored fiber cables do not conduct electricity, which makes fiber a good solution for protecting communications equipment located in high voltage environments. They can also be used in environments where explosive fumes are present, without danger of ignition. Wiretapping is more difficult compared to electrical connections, and there are concentric dual core fibers that are said to be tap-proof.

Although fibers can be made out of transparent plastic, glass, or a combination of the two, the fibers used in long-distance telecommunications applications are always glass, because of the lower optical attenuation. Both multi-mode and single-mode fibers are used in communications, with multi-mode fiber used mostly for short distances up to 550 m, and single-mode fiber used for longer distance links. Because of the tighter tolerances required to couple light into and between single-mode fibers, single-mode transmitters, receivers, amplifiers and other components are generally more expensive than multi-mode components.

B. Fiber optic 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 time-domain reflect meter.

Optical fibers can be used as sensors to measure strain, temperature, pressure and other quantities. 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 provide distributed sensing over distances of up to one meter.

Extrinsic fiber optic sensors use an optical fiber cable, normally a multimode 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 places which are otherwise inaccessible. An example is the measurement of temperature inside jet engines by using a fiber to transmit radiation into a radiation pyrometer located outside the engine. Extrinsic sensors can also 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 are used to measure vibration, rotation, displacement, velocity, acceleration, torque, and twisting.

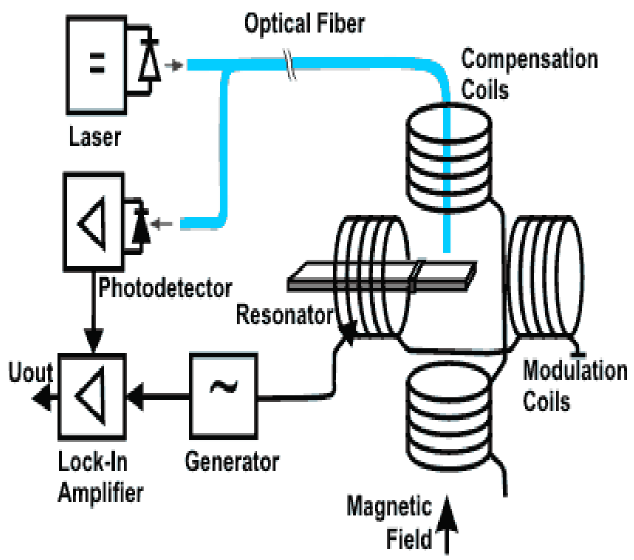

Figure 4: Principal scheme of fiber optic magnetic filed sensor.

IV. Conclusion

Optical fiber development changed the communication world today because optical fiber provides an attractive alternative to wire transmission lines and its advantages over copper in many aspects like high bandwidth, low attenuation, noise susceptibility, secure communication and low cost.

Also optical fiber development have founded solution to sensors in extreme surrounding that make other measurement techniques impossible to work in.

From all of that and more we see the importance of optical fiber in today technology and how will it shape the future.

References

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