OPTICAL FIBER

Definitions

An **optical fiber** is a glass or plastic fiber designed to guide light along its length, widely used in fiber-optic communication, which permits transmission over longer distances and at higher data rates than other forms of communications.

Fiber-optic communication is a method of transmitting information from one place to another by sending light through an optical fiber.

Basics

An **optical fiber** is a thin fiber of glass or plastic that can carry light from one end to the other. The study of optical fibers is called fiber optics, which is part of applied science and engineering.

Optical fibers are mainly used in telecommunications, but they are also used for lighting, sensors, toys, and special cameras for seeing inside small spaces.

How it works

An optical fiber is a long, thin strand of clear material. Its shape is usually similar to a cylinder. In the center, it has a core. Around the core is a layer called the cladding. The core and cladding are made of different kinds of glass or plastic, so that light travels slower in the core than it does in the cladding. If the light in the core hits the edge of the cladding at a shallow angle, it bounces off. Light can travel inside the core and bounce off of the cladding. No light escapes until it comes to the end of the fiber, unless the fiber is bent or stretched.

If the cladding of the fiber is scratched, it may break. A plastic coating called the buffer covers the cladding to protect it. Often, the buffered fiber is put inside an even tougher layer, called the jacket. This makes it easy to use the fiber without breaking it.

Uses

The main use of optical fiber is in long-distance communication (telecommunication). Since the light does not leak out of the fiber much as it travels, the light can go a long distance before the signal gets too weak. This is used to send telephone and internet signals between cities.

Fiber is sometimes used for shorter links too, such as to carry the sound signals between a compact disc player and a stereo receiver. The fibers used for these short links are often made of plastic. TOSLINK is the most common type of optical plug for stereos.

Optical fibers can be used as lasers. Special fibers are used for this, that change how they pass light through when there is a change around the fiber. Sensors like this can be used to detect changes in temperature, pressure, and other things. These sensors are useful because they are small and do not need any electricity at the place where the sensing happens.

These fibers are also used to carry light for humans to see. This is sometimes used for decoration, like fiber-optic Christmas trees. Sometimes it is used for lighting, when it is convenient to have the light bulb someplace other than where the light needs to be. This is sometimes used in signs and art for special effects.

A bundle of fibers can be used to make a device called an endoscope or a fiberscope. This is a long thin probe that can be put into a small hole, that will send an image of what is inside through the fiber to a camera. Endoscopes are used by doctors to see inside the human body, and are sometimes used by engineers to see inside tight spaces in machines.

Lasers can be made out of optical fiber too. These are called fiber lasers. They are very powerful, because the long thin fiber is easy to keep cool, and makes a good quality light beam.

Topics of Interest

An optical fiber is a glass or plastic fiber that carries light along its length. Fiber optics is the overlap of applied science and engineering concerned with the design and application of optical fibers. Optical fibers are widely used in fiber-optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) than other forms of communications. Fibers are used instead of metal wires because signals travel along them with less loss, and they are also immune to electromagnetic interference. Fibers are also used for illumination, and are wrapped in bundles so they can be used to carry images, thus allowing viewing in tight spaces. Specially designed fibers are used for a variety of other applications, including sensors and fiber lasers.

Light is kept in the core of the optical fiber by total internal reflection. This causes the fiber to act as a waveguide. Fibers which support many propagation paths or transverse modes are called multi-mode fibers (MMF), while those which can only support a single mode are called single-mode fibers (SMF). Multi-mode fibers generally have a larger core diameter, and are 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 (1,800 ft).

Joining lengths of optical fiber is more complex than joining electrical wire or cable. The ends of the fibers must be carefully cleaved, and then spliced together either mechanically or by fusing them together with an electric arc. Special connectors are used to make removable connections.

Fiber optics, though used extensively in the modern world, is a fairly simple and old technology. Guiding of light by refraction, the principle that makes fiber optics possible, was first demonstrated by Daniel Colladon and Jacques Babinet in Paris in the early 1840s.

NASA used fiber optics in the television cameras that were sent to the moon. At the time its use in the cameras was 'classified confidential' and only those with the right security clearance or those accompanied by someone with the right security clearence were permitted to handle the cameras.

In 1991, the emerging field of photonic crystals led to the development of photonic-crystal fiber which guides light by means of diffraction from a periodic structure, rather than total internal reflection. The first photonic crystal fibers became commercially available in 2000. Photonic crystal fibers can be designed to carry higher power than conventional fiber, and their wavelength dependent properties can be manipulated to improve their performance in certain applications.

Applications

Optical fiber communication

Optical fiber can be used as a medium 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. This allows long distances to be spanned with few repeaters. Additionally, the light signals propagating in the fiber can be modulated at rates as high as 40 Gb/s, and each fiber can carry many independent channels, each by a different wavelength of light (wavelength-division multiplexing). Over short distances, such as networking within a building, 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 interference, which prevents cross-talk between signals in different cables and pickup of environmental noise. Also, wiretapping is more difficult compared to electrical connections, and there are concentric dual core fibers that are said to be tap-proof. Because they are non-electrical, fiber cables can bridge very high electrical potential differences and can be used in environments where explosive fumes are present, without danger of ignition.

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 500 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 (core diameter about 10 micrometers), single-mode transmitters, receivers, amplifiers and other components are generally more expensive than multi-mode components.

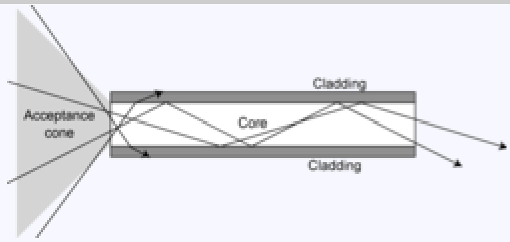
Fiber optic sensors

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-fiberoptic 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 reflectometer.

Principle of operation

Multimode fiber

Multi-mode optical fiber (multimode fiber or MM fiber or fibre) is a type of optical fiber mostly used for communication over shorter distances, such as within a building or on a campus. Typical multimode links have data rates of 10 Mbit/s to 10 Gbit/s over link lengths of up to 600 meters—more than sufficient for the majority of premises applications.



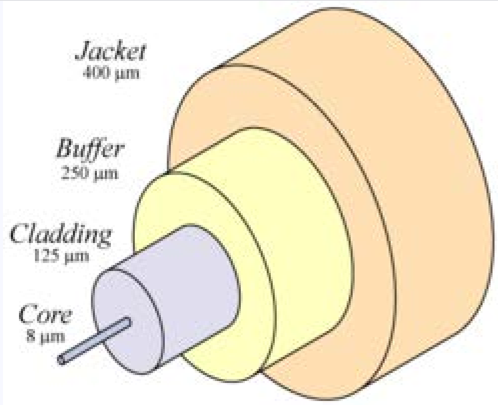
The propagation of light through a multi-mode optical fiber.

Fiber with large (greater than 10 μm) core diameter may be analyzed by geometric optics. Such fiber is called multimode fiber, from the electromagnetic analysis (see below). In a step-index multimode 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. A low numerical aperture may therefore be desirable.

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.

Singlemode fiber

In fiber-optic communication, a **single-mode optical fiber (SMF)** (monomode optical fiber, single-mode optical waveguide, or unimode fiber) is an optical fiber designed to carry only a single ray of light (mode). This ray of light often contains a variety of different wavelengths. Although the ray travels parallel to the length of the fiber, it is often called the transverse mode since its electromagnetic vibrations occur perpendicular (transverse) to the length of the fiber. The 2009 Nobel Prize for Physics was given to Charles K. Kao for his theoretical work on the single-mode optical fiber.



A typical single-mode optical fiber, showing diameters of the component layers.

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 multimode 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.

The waveguide analysis shows that the light energy in the fiber is not completely confined in the core. Instead, especially in single-mode fibers, a significant fraction of the energy in the bound mode travels in the cladding as an evanescent wave.

The most common type of single-mode fiber has a core diameter of 8 to 10 µm and is designed for use in the near infrared. The mode structure depends on the wavelength of the light used, so that this fiber actually supports a small number of additional modes at visible wavelengths. Multi-mode fiber, by comparison, is manufactured with core diameters as small as 50 microns and as large as hundreds of microns.

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