Let There Be Light

How fiber optics really works

By Buddy Oliver

An easy way to understand how fiber optics works: visualize peering into a very long tube, the inside of which is coated with a perfectly mirrored surface. One mile away, at the opposite end, a friend shines a bright flashlight into the tube.

Because the tube is internally coated with a mirror, you'll see his light clearly at your end, regardless of how many twists and turns the pipe takes. If your friend flashes the light off and on repeatedly (simulating a binary off/on electronic pulse), you'll see this "digital" light data at your end - literally, at the speed of light.

Most optical fibers for communications applications are made of silica glass that consists of a solid inner core surrounded by a cladding layer of glass with a lower index of refraction than the core. The boundary between the core and the cladding causes an internal reflection so that light entering the core at one end remains trapped until it emerges at the other end.

Light sent through the fiber is most commonly generated by either an LED or a laser. These specialized optical transmitters "flash" the light to represent digital binary data, either on or off. The modulated light is sent at very fast data transmission rates, typically from 125 Mbs (mega millions of bits per second) to 10 Gbs (mega billions of bits per second) - and faster. The light "data" passes through the entire length of the fiber and is detected at the other end by an optical receiver that converts the pulsing light back into an electrical signal.

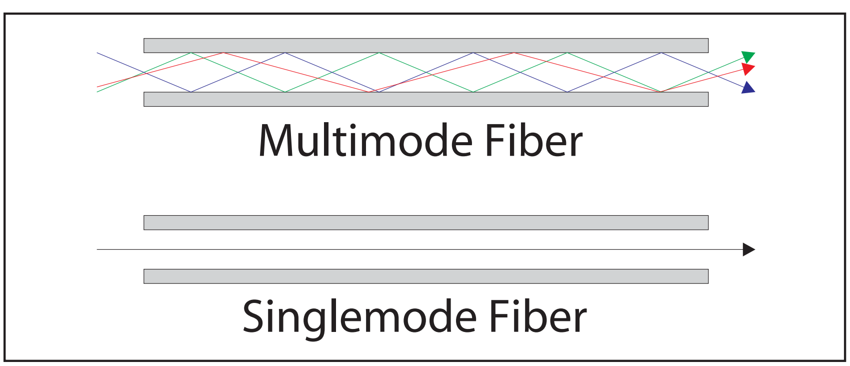
Optical fibers are designed to operate in either "multimode" or "singlemode" applications. Singlemode fibers will only accept light rays entering parallel to the axis of the fiber's core. Multimode fibers will accept light rays entering at angles of up to 25 degrees off-axis. By accepting a wider range of angular displacement, the light rays entering at wider angles must travel a longer distance for a given length of fiber.

This difference in distance results in a minute variation in arrival time for light rays entering at different angles. Variations in this arrival time become proportionally greater as the length of the fiber and/or the data rate increases.

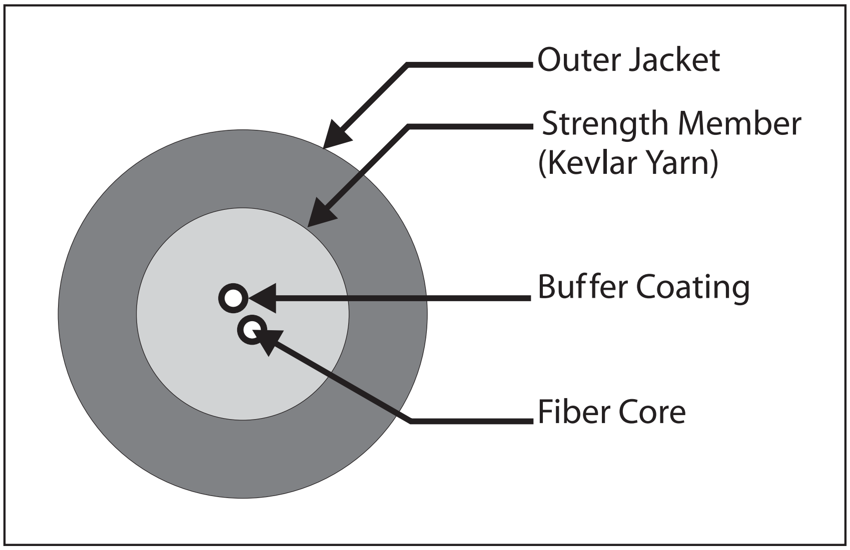
Singlemode fiber overcomes this limitation of multimode fiber and can achieve much longer transmission ranges; however, due to the accuracy necessary to produce light entering parallel to the fiber core's axis, singlemode systems are typically more expensive.

One common concern about using fiber optic cable is its durability. Fiber cable comes with various types of jacketing which can provide equal if not greater durability than its copper equivalents.

A single strand of glass fiber is only slightly larger in diameter than a human hair. Layers of protective material surround this fiber "core". Standard installed fiber usually comes with a PVC jacket. "Plenum cable," a higher-rated grade, comes with a fire-



A comparison of the light paths in multimode and singlemode fiber.



A cross section of a two-channel tactical fiber.

retardant coating (usually Teflon) so that it does not give off toxic gasses and smoke should it burn.

"Tactical fiber," with the highest grade jacketing, is specifically designed for quick and easy deployment in rugged, harsh environments. It's engineered and manufactured to meet the stringent environmental and mechanical requirements of the U.S. military. These various grades of jacketing provide increasing levels of durability, but all are as flexible as their equivalent diameter copper cables.

The most common types of fiber optic connectors used are "ST" and "SC" connectors. Both can be field-terminated and are the most useful in permanent fiber installations. TFOCA (Tactical Fiber Optic Cable Assembly) and TFOL (Tactical Fiber Optic Link) connectors provide a higher level of durability.

These connectors are designed to be used with tactical fiber in harsh military field applications and have been adapted for use in numerous demanding commercial applications as well.

THE PLUS SIDE

There are benefits to using fiber optic rather than copper cable. Some of the most important advantages concern fiber's inherently superior dielectric properties. Because optical fiber has no metallic components, it's unsurpassed for providing complete electrical isolation as well as noise immunity.

Electrical isolation is most important when it comes to eliminating ground loops. A ground loop is a condition where an unintended connection to ground is made through an interfering electrical conductor.

Generally, a ground loop connection exists when an electrical system is connected in more than one way to an electrical ground. Because there is no electrical conduction through fiber cable, equipment grounded at one end of the connection is completely isolated from the ground at the other end.

Ground loops can be an especially irritating source of headaches in even the simplest sound systems and thus, using optical fiber signal transmission can eliminate these major sources of problems - entirely.

Another advantage of optical fiber is its immunity to external noise. Electrical noise, also known as EMI (electromagnetic interference), and RFI (radio frequency interference), are unwanted electrical signals that produce undesirable effects and otherwise disrupt audio and data systems.

Sources of EMI/RFI include lighting equipment, computers, electric motors, and radio and television broadcasts. Fluorescent lights and power lines are a common source of annoying 60 Hz hum. Lightning can also be a common natural source of audio and data system interference and disruption.

The interference from all these sources modifies and interacts with data signals in metal cables, causing data errors and transient unreliability. Even traditional high-quality "balanced" copper cables are susceptible to EMI/RFI and lightning problems.

The low signal attenuation performance and superior signal integrity found in fiber optical systems facilitates much longer runs for signal transmission than metal-based systems. While single-line, voice-grade copper systems require in-line signal repeaters for satisfactory performance over long distances, it's common for multimode optical systems to extend to two kilometers (km) - about 1.25 miles - or for singlemode fiber systems to reach up to 20 or more km - about 12.5 miles - with no active or passive processing. Emerging technologies for fiber optics promise even greater distances in the future.

Long, continuous lengths and the small diameters of fiber optic cable runs provide numerous advantages for installers and end-users. Since today's applications require an ever-increasing amount of bandwidth, it is important to consider space constraints.

It's commonplace to install new fiber optic cabling within existing HVAC duct systems. The relatively small diameter and light weight of optical cables makes such installations both easier and practical and also saves valuable electrical conduit space.

System designers typically plan optical systems that will meet growth needs for a 15- to 20-year life span. Although sometimes difficult to predict, potential growth can be accommodated by installing spare fiber cables for future requirements. Installation of spare fibers today is more economical than installing additional ones later. In addition, with the use of multiplexing technology, additional channels can be carried over the same fiber cable by simply upgrading the hardware at either end.

As bandwidth demands increase rapidly with technological advances, and prices continue to drop, fiber will continue to play a vital role in the long-term success of more reliable communications.

A single strand of glass fiber is only slightly larger in diameter than a human hair

KEY FIBER OPTIC TERMS

Bandwidth: A measurement of the information-carrying capacity of an optical fiber. Note: This term is often used to specify the normalized modal bandwidth (MHz·km) of a multimode fiber. See "Dispersion" (below) for single-mode fibers.

Cladding: The material surrounding the core of an optical waveguide. The cladding must have a lower index of refraction to keep the light in the core.

Dielectric: Non-metallic and, therefore, non-conductive. Glass fibers are considered dielectric. A dielectric cable contains no metallic components.

Dispersion: The cause of bandwidth limitations in a fiber. Dispersion causes a broadening of input pulses along the length of the fiber. Three major types are: 1) modal dispersion caused by differential optical path lengths in a multimode fiber; 2) chromatic dispersion caused by a differential delay of various wavelengths of light in a waveguide material; and 3) waveguide dispersion caused by light traveling in both the core and cladding materials in single-mode fibers.

Electro Magnetic Interference (EMI): Electrical noise, or EMI, are unwanted electrical signals that produce undesirable effects and otherwise disrupt the control and degrade the fidelity of system circuits. EMI may be either radiated or conducted. When the noise originates from a source and travels through the air it is called radiated. Conducted noise travels on an actual conductor, like a power line. The original noise may have been radiated, coupled into the lines, and then conducted.

Ferrule: A mechanical fixture (generally a rigid polymer or metal tube) used to protect and align a fiber in a connector. Generally associated with fiber optic connectors.

Fiber: Thin filament of glass. An optical waveguide consisting of a core and a cladding that is capable of carrying information in the form of light.

Fiber Bend Radius: The radius a fiber can bend before the risk of breakage or an increase in signal attenuation.

Minimum Bend Radius: The amount of bend a fiber (or cable) can withstand before experiencing problems in performance.

Graded-Index: Fiber optic cable design in which the refractive index of the core is lower toward the outside of the fiber core and increased toward the center of the core; thus, light rays are focused inward which allows them to travel faster in the lower index of refraction region. This type of fiber provides higher bandwidth capabilities for multimode fiber transmission.

Three standard fiber connectors, left to right: ST, FC and SC.

Wavelength: The distance between two successive points of an electromagnetic waveform, usually measured in nanometers (nm).

LASER Diode: Light Amplification by Stimulated Emission of Radiation. An electro-optic device that produces coherent light within a narrow range of wavelengths, typically centered around 780 nm, 1310 nm, or 1550 nm. Lasers with wavelengths centered around 780 nm are commonly referred to as CD Lasers.

Light Emitting Diode (LED): A semiconductor device used to transmit light into a fiber in response to an electrical signal. It typically has a broad spectral width.

Mode: A term used to describe an independent light path through a fiber, as in multimode or singlemode.

Multimode Fiber (MM): An optical waveguide in which light travels in multiple modes. Typical core/cladding size is 62.5µm /125µm (measured in micrometers).

Multiplex: Combining two or more signals into a single bit stream that can be individually recovered.

PVC: Abbreviation used to denote polyvinyl-chloride. A type of plastic material used for cable jacketing. Typically used in flame-retardant cables.

The TFOL(tm) tactical connector used in the FiberPlex Light Viper system.

Plenum: An air-handling space such as that found above drop-ceiling tiles or in raised floors. Also, a fire-code rating for indoor cable.

Radio Frequency Interference - (RFI): Electromagnetic radiation which is emitted by electrical circuits carrying rapidly changing signals, as a by-product of their normal operation, and which causes unwanted signals (interference or noise) to be induced in other circuits.

Singlemode Fiber (SM): An optical waveguide (or fiber) in which the signal travels in one mode. The fiber has a small core diameter, typically 8.3 µm. ■

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