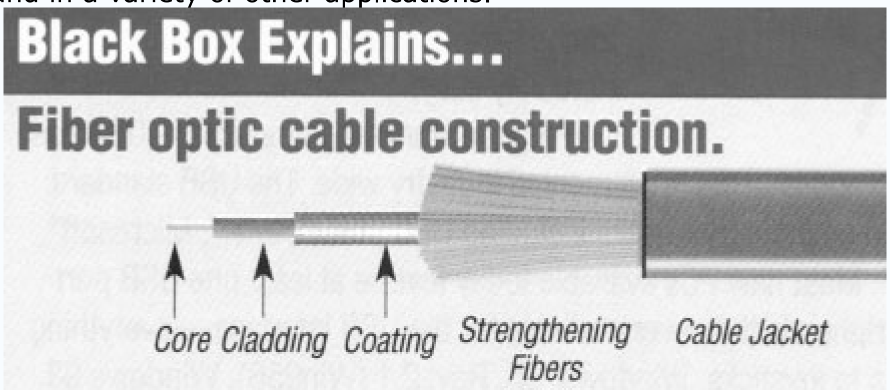
Optical Fiber Communication

Overview:

An **optical fiber** is a glass or plastic fiber designed to guide light along its length by total internal reflection. **Fiber optics** is the branch of applied science and engineering concerned with such optical fibers. Optical fibers are widely used in fiber-optic communication, which permits digital data transmission over longer distances and at higher data rates than electronic communication. They are also used to form sensors, and in a variety of other applications.



The operating principle of optical fibers applies to a number of variants including single-mode optical fibers, graded-index optical fiber, and step-index optical fibers. Because of the physics of the optical fiber, special methods of splicing fibers and of connecting them to other equipment are needed. A variety of methods are used to manufacture optical fibers, and the fibers are also built into different kinds of cables depending on how they will be used.

History

The light-guiding principle behind optical fibers was first demonstrated in Victorian times, but modern optical fibers were only developed beginning in the 1950's. Optical fiber was developed in **1970** by Corning Glass Works with attenuation low enough for communication purposes (about 20dB/km), and at the same time GaAs semiconductor lasers were developed that were compact and therefore suitable for fiber-optic communication systems.

After a period of intensive research from 1975 to 1980, **the first commercial fiber-optic communication system** was developed, which operated at a wavelength around 0.8 µm and used GaAs semiconductor lasers. This "first generation" system operated at a bit rate of 45 Mb/s with repeater spacing of up to 10km.

The "second generation" of fiber-optic communication was developed for commercial use in the early 1980's, operated at 1.3 µm, and used InGaAsP semiconductor lasers.

Third-generation fiber-optic systems operated at 1.55 µm and had loss of about 0.2-dB/km. They achieved this despite earlier difficulties with pulse-spreading at that wavelength using conventional InGaAsP semiconductor lasers.

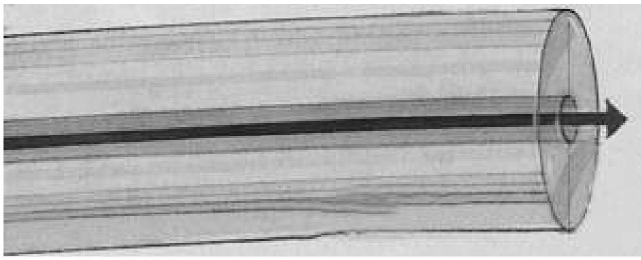
The fourth generation of fiber-optic communication systems used optical amplification to reduce the need for repeaters and wavelength-division multiplexing to increase fiber capacity.

The focus of development for the **fifth generation of fiber-optic communications** is on extending the wavelength range over which a WDM system can operate.

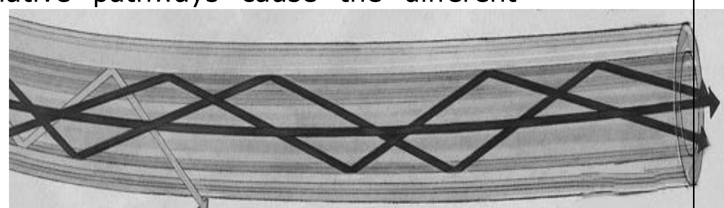
In the late 1990s through 2000, the fiber optic communication industry became associated with the dot-com bubble. Industry promoters and research companies such as KMI and RHK predicted vast increases in demand for communications bandwidth due to increased use of the Internet.

Types of optical fiber:

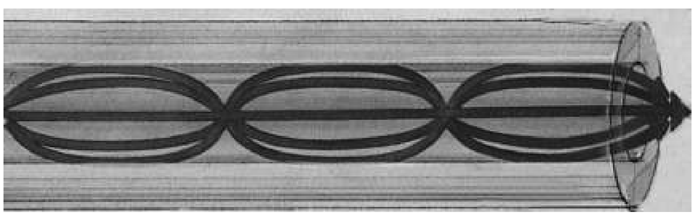
SINGLE-MODE FIBER has a narrow core (eight microns or less), and the index of refraction between the core and the cladding changes less than it does for multimode fibers. Light thus travels parallel to the axis, creating little pulse dispersion. Telephone and cable television networks install millions of kilometers of this fiber every year.



STEP-INDEX MULTIMODE FIBER has a large core, up to 100 microns in diameter. As a result, some of the light rays that make up the digital pulse may travel a direct route, whereas others zigzag as they bounce off the cladding. These alternative pathways cause the different groupings of light rays, referred to as modes, to arrive separately at a receiving point. The pulse, an aggregate of different modes, begins to spread out, losing its well-defined shape. The need to leave spacing between pulses to prevent overlapping limits bandwidth that is, the amount of information that can be sent. Consequently, this type of fiber is best suited for transmission over short distances, in an endoscope, for instance.



GRADED-INDEX MULTIMODE FIBER contains a core in which the refractive index diminishes gradually from the center axis out toward the cladding. The higher refractive index at the center makes the light rays moving down the axis advance more slowly than those near the cladding. Also, rather than zigzagging off the cladding, light in the core curves helically because of the graded index, reducing its travel distance. The shortened path and the higher speed allow light at the periphery to arrive at a receiver at about the same time as the slow but straight rays in the core axis. The result: a digital pulse suffers less dispersion.

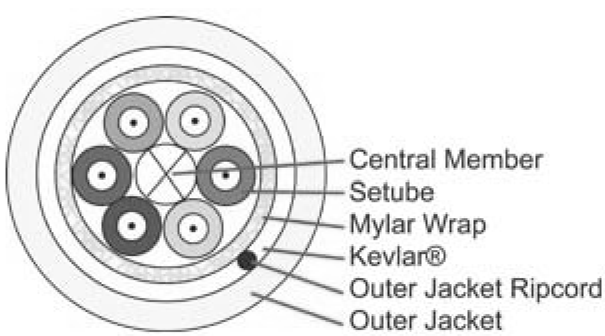


BASIC CABLE DESIGN

Two basic cable designs are:

1- Loose-Tube Cable:

Loose-tube cable, used in the majority of outside-plan installations in North America, and tight-buffered cable, primarily used inside buildings.

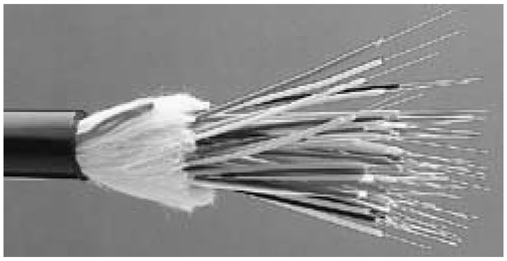


The modular design of loose-tube cables typically holds up to 12 fibers per buffer tube with a maximum per cable fiber count of more than 200 fibers. Loose-tube cables can be all-dielectric or optionally armored. In a loose-tube cable design, color-coded plastic buffer tubes house and protect optical fibers. A gel filling compound impedes water penetration. Excess fiber length (relative to buffer tube length) insulates fibers from stresses of installation and environmental loading. Buffer tubes are stranded around a dielectric or steel central member, which serves as an anti-buckling element.

The cable core typically uses aramid yarn, as the primary tensile strength member. The outer polyethylene jacket is extruded over the core. If armoring is required, a corrugated steel tape is formed around a single jacketed cable with an additional jacket extruded over the armor.

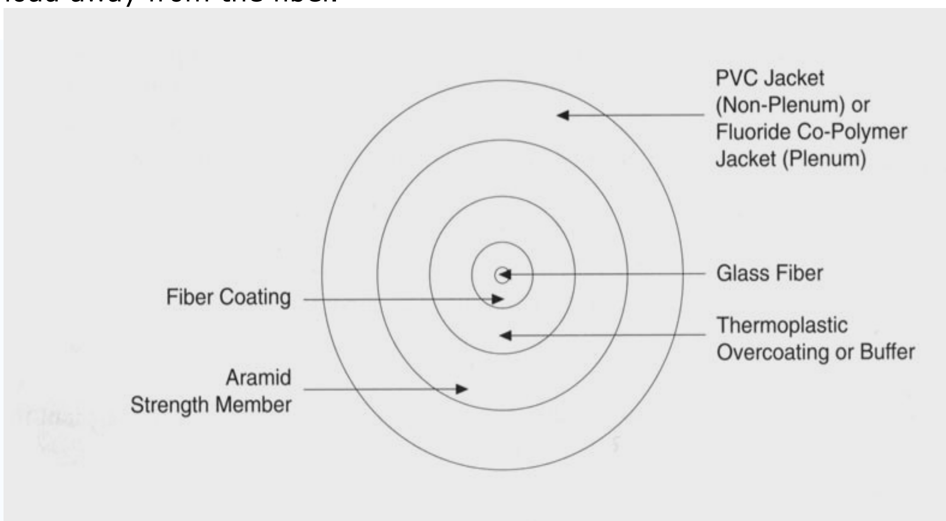
2-Tight-Buffered Cable

With tight-buffered cable designs, the buffering material is in direct contact with the fiber. This design is suited for "jumper cables" which connect outside plant cables to terminal equipment, and also for linking various devices in a premises network.



Multi-fiber, tight-buffered cables often are used for intra-building, risers, general building and plenum applications.

The tight-buffered design provides a rugged cable structure to protect individual fibers during handling, routing and connectorization. Yarn strength members keep the tensile load away from the fiber.



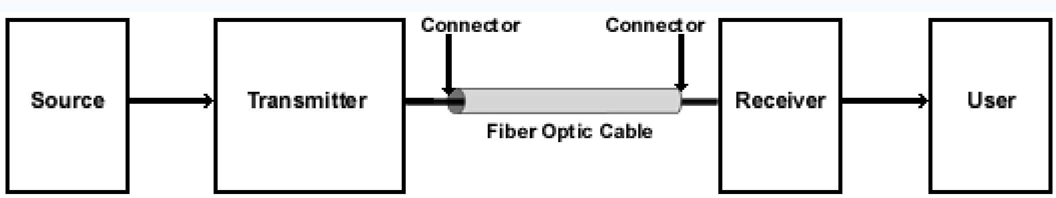
Tight-Buffered Cable

Communication Applications

Fiber-optic cable is used by many telecommunications companies to transmit telephone signals, internet communication, and cable television signals, sometimes all on the same optical fiber.

Communication System Using Optical Fiber

Modern fiber-optic communication systems generally include an optical transmitter to convert an electrical signal into an optical signal to send into the optical fiber, a fiber-optic cable routed through underground conduits and buildings, multiple kinds of amplifiers, and an optical receiver to recover the signal as an electrical signal.



Components of the Transmission System:

Transmitters: The most commonly used optical transmitters are **semiconductor** devices such as **Light-emitting diodes** (LEDs) and **laser diodes**. The difference between LEDs and laser diodes is that LEDs produce incoherent light, while laser diodes produce coherent light. Semiconductor optical transmitters are compact, efficient, and reliable, operate in an optimal wavelength range, and can be directly modulated at high frequencies, making them well-suited for fiber-optic communication applications.

In its simplest form, a LED is a forward-biased p-n junction, emitting light through spontaneous emission, a phenomenon referred to as electroluminescence. The emitted light is incoherent with a relatively wide spectral width of 30-60 nm. LED light transmission is also inefficient, with only about 1% of input power, or about 100 microwatts, eventually converted into "launched power" which has been coupled into the optical fiber. However, due to their relatively simple design, LEDs are very useful for low-cost applications.

A **semiconductor** laser emits light through stimulated emission rather than spontaneous emission, which results in high output power (~100 mW) as well as other benefits related to the nature of coherent light. The output of a laser is relatively directional, resulting in high coupling efficiency (~50%) into single-mode fiber. The narrow spectral width also allows for high bit rates since modal dispersion is less apparent. Furthermore, semiconductor lasers can be modulated directly at high frequencies because of short recombination time.

Laser diodes are often directly modulated, that is the light output is controlled by a current applied directly to the device. For very high data rates or very long distance *links*, a laser source may be operated continuous wave, and the light modulated by an external device such as an electro absorption modulator or Mach-Zehnder interferometer. External modulation increases the achievable link distance by eliminating laser chirp, which broadens the line width of directly-modulated lasers, increasing the chromatic dispersion in the fiber.

Amplifiers:

The transmission distance of a fiber-optic communication system has traditionally been limited primarily by fiber attenuation and second by fiber distortion. The solution to this has been to use opto-electronic repeaters. These repeaters first convert the signal to an electrical signal then use a transmitter to send the signal again at a higher intensity. Because of their high complexity, especially with modern wavelength-division multiplexed signals, and the fact that they had to be installed about once every 20km, the cost for these repeaters was very high.

An alternative approach is to use an optical amplifier, which amplifies the optical signal directly without having to convert the signal into the electrical domain. Made by doping a length of fiber with the rare-earth mineral erbium, and pumping it with light from a laser with a shorter wavelength than the communications signal (typically 980 nm), amplifiers have largely replaced repeaters in new installations.

Receivers

The main component of an optical receiver is a photo detector that converts light into electricity through the photoelectric effect. The photo detector is typically a semiconductor-based photodiode, such as a p-n photodiode, a p-i-n photodiode, or an avalanche photodiode. Metal-semiconductor-metal (MSM) photo detectors are also used due to their suitability for circuit integration in regenerators and wavelength-division multiplexers.

The optical-electrical converters is typically coupled with a Tran impedance amplifier and limiting amplifier to produce a digital signal in the electrical domain from the incoming optical signal, which may be attenuated and distorted by passing through the channel. Further signal processing such as clock recovery from data (CDR) by a phase-locked loop may also be applied before the data is passed on.

Wavelength-Division Multiplexing:

Wavelength-division multiplexing (WDM) is the practice of dividing the wavelength capacity of an optical fiber into multiple channels in order to send more than one signal over the same fiber. This requires a wavelength division multiplexer in the transmitting equipment and a wavelength division demultiplexer (essentially a spectrometer) in the receiving equipment. Arrayed waveguide gratings are commonly used for multiplexing and demultiplexing in WDM. Using WDM technology now commercially available, the bandwidth of a fiber can be divided into as many as 80 channels to support a combined bit rate into the range of terabits per second.

Wavelength-division multiplexing, and optical amplifiers, modern-day optical fibers can carry information at around 14 Terabits per second over 160 kilometers of fiber [2]. Engineers are always looking at current limitations in order to improve fiber-optic communication.

Attenuation

Fiber attenuation, which necessitates the use of amplification systems, is caused by a combination of material absorption, Raleigh scattering, Mie scattering, and connection losses. Although material absorption for pure silica is only around 0.03db/km (modern fiber has attenuation around 0.3 db/km), impurities in the original optical fibers caused attenuation of about 1000 db/km. The root causes of the other forms of attenuation are physical stresses to the fiber, microscopic fluctuations in density, and imperfect splicing techniques.

Comparison with electrical transmission

The choice between optical fiber and electrical (or "copper") transmission for a particular system is made based on a number of trade-offs. Optical fiber is generally chosen for systems with higher bandwidths or spanning longer distances than electrical cabling can provide. **The main benefits of fiber** are its exceptionally low loss, allowing long distances between amplifiers or repeaters; and its inherently high data-carrying capacity, such that thousands of electrical links would be required to replace a single high bandwidth fiber. Another benefit of fiber is that even when run alongside each other for long distances, fiber cables experience effectively no crosstalk, in contrast to some types of electrical transmission lines.

In short distance and relatively low bandwidth applications**, electrical transmission** is often preferred.

In certain situations fiber may be used even for short distance or low bandwidth applications, due to other important features:

1- Immunity to electromagnetic interference, including nuclear electromagnetic pulses (although fiber can be damaged by alpha and beta radiation).
2- High electrical resistance, making it safe to use near high-voltage equipment or between areas with different earth potentials.
3- Lighter weight, important, for example, in aircraft.
4- No sparks, important in flammable or explosive gas environments.
5- Not electromagnetically radiating, and difficult to tap without disrupting the signal, important in high-security environments.
6- Much smaller cable size - important where pathway is limited.

The advantages of optical fibres over conventional copper wires are:

1)Less expensive - Several miles of optical cable can be made cheaper than equivalent lengths of copper wire.

2)Higher carrying capacity - Because optical fibres are thinner than copper wires, more fibres can be bundled into a given-diameter cable than copper wires. This allows more phone lines to go over the same cable or more channels to come through the cable into your cable TV box.

3)Less signal degradation - The loss of signal in optical fibre is less than in copper wire. 4)Light signals - Unlike electrical signals in copper wires, light signals from one fibre do not interfere with those of other fibres in the same cable. This means clearer phone conversations or TV reception.

5)Digital signals - Optical fibres are ideally suited for carrying digital information, which is especially useful in computer networks.

6)Non-flammable - Because no electricity is passed through optical fibres, there is no fire hazard.

7)Lightweight and thin - An optical cable weighs less than a comparable copper wire cable. Optical fibres can be drawn to smaller diameters than copper wire. Fibre-optic cables take up less space in the ground.

The disadvantages of optical fibres are

Price - Even though the raw material for making optical fibres, sand, is abundant(1 and cheap, optical fibres are still more expensive per metre than copper. Although, one fibre can carry many more signals than a single copper cable and the large .transmission distances mean that fewer expensive repeaters are required

.Fragility - Optical fibres are more fragile than electrical wires(2

Affected by chemicals - The glass can be affected by various chemicals including(3 (.hydrogen gas (a problem in underwater cables

Opaqueness - Despite extensive military use it is known that most fibres become(4 .opaque when exposed to radiation

Requires special skills - Optical fibres cannot be joined together as a easily as(5 copper cable and requires additional training of personnel and expensive precision .splicing and measurement equipment

The End

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