http://en.wikipedia.org/wiki/Fiber-optic_communication

Fiber-optic communication

Fiber-optic communication is a method of transmitting information from one place to another by sending light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. First developed in the 1970s, fiber-optic communication systems have revolutionized the telecommunications industry and played a major role in the advent of the Information Age. Because of its advantages over electrical transmission, the use of optical fiber has largely replaced copper wire communications in the developed world.

The process of communicating using fiber-optics involves the following basic steps:

- Creating the optical signal using a transmitter
- Relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak
- Receiving the optical signal and converting it into an electrical signal

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.

Due to much lower attenuation and interference, optical fiber has large advantages over existing copper wire in long-distance and high-demand applications. However, infrastructure development within cities was relatively difficult and time-consuming, and fiber-optic systems were complex and expensive to install and operate. Due to these difficulties, fiber-optic communication systems have primarily been installed in long-distance applications, where they can be used to their full transmission capacity, offsetting the increased cost. Since the year 2000, the prices for fiber-optic communications have dropped considerably. The price for rolling out fiber to the home has currently become more cost-effective than that of rolling out a copper based network. Prices have dropped to $850 per subscriber in the US and lower in countries like The Netherlands, where digging costs are low.

Since 1990, when optical-amplification systems became commercially available, the telecommunications industry has laid a vast network of intercity and transoceanic fiber communication lines. By 2002, an intercontinental network of 250,000 km of submarine communications cable with a capacity of 2.56 Tb/s was completed, and although specific network capacities are privileged information, telecommunications investment reports indicate that network capacity has increased dramatically since 2002.

History

The need for reliable long-distance communication systems has existed since antiquity. Over time, the sophistication of these systems has gradually improved, from smoke signals to telegraphs and finally to the first coaxial cable, put into service in 1940. As these communication systems improved, certain fundamental limitations presented themselves. Electrical systems were limited by their small repeater spacing (the distance a signal can propagate before attenuation requires the signal to be amplified), and the bit rate of microwave systems was limited by their carrier frequency. In the second half of the twentieth century, it was realized that an optical carrier of information would have a significant advantage over the existing electrical and microwave carrier signals.

However, no coherent light source or suitable transmission medium was available. Then, after the development of lasers in the 1960s solved the first problem, development of high-quality optical fiber was proposed as a solution to the second. Optical fiber was finally 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 Mbit/s with repeater spacing of up to 10 km.

On 22 April, 1977, General Telephone and Electronics sent the first live telephone traffic through fiber optics, at 6 Mbit/s, in Long Beach, California.

The *second generation* of fiber-optic communication was developed for commercial use in the early 1980s, operated at 1.3 µm, and used InGaAsP semiconductor lasers. Although these systems were initially limited by dispersion, in 1981 the single-mode fiber was revealed to greatly improve system performance. By 1987, these systems were operating at bit rates of up to 1.7 Gb/s with repeater spacing up to 50 km.

The first transatlantic telephone cable to use optical fiber was TAT-8, based on Desurvire optimized laser amplification technology. It went into operation in 1988.

TAT-8 was developed as the first transatlantic undersea fiber optic link between the United States and Europe. TAT-8 is more than 3000 nautical miles in length and was the first oceanic fiber optic cable. It was designed to handle a mix of information. When inaugurated, it had an estimated lifetime in excess of 20 years. TAT-8 was the first of a new class of cables, even though it had already been used in long-distance land and short-distance undersea operations. Its installation was preceded by extensive deep-water experiments and trials conducted in the early 1980s to demonstrate the project's feasibility.

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. Scientists overcame this difficulty by using dispersion-shifted fibers designed to have minimal dispersion at 1.55 μm or by limiting the laser spectrum to a single longitudinal mode. These developments eventually allowed 3rd generation systems to operate commercially at 2.5 Gbit/s with repeater spacing in excess of 100 km.

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. These two improvements caused a revolution that resulted in the doubling of system capacity every 6 months starting in 1992 until a bit rate of 10 Tb/s was reached by 2001. Recently, bit-rates of up to 14 Tbit/s have been reached over a single 160 km line using optical amplifiers.

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. The conventional wavelength window, known as the C band, covers the wavelength range 1.53-1.57 μm, and the new *dry fiber* has a low-loss window promising an extension of that range to 1.30 to 1.65 μm. Other developments include the concept of "optical solitons, " pulses that preserve their shape by counteracting the effects of dispersion with the nonlinear effects of the fiber by using pulses of a specific shape.

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, and commercialization of various bandwidth-intensive consumer services, such as video on demand. Internet protocol data traffic was said to be increasing exponentially, and at a faster rate than integrated circuit complexity had increased under Moore's Law. From the bust of the dot-com bubble through 2006, however, the main trend in the industry has been consolidation of firms and offshoring of manufacturing to reduce costs.

Technology

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. The information transmitted is typically digital information generated by computers, telephone systems, and cable television companies.

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. For use in optical communications, semiconductor optical transmitters must be designed to be compact, efficient, and reliable, while operating in an optimal wavelength range, and directly modulated at high frequencies.

In its simplest form, an 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.

Communications LEDs are most commonly made from gallium arsenide phosphide (GaAsP) or gallium arsenide (GaAs). Because GaAsP LEDs operate at a longer wavelength than GaAs LEDs (1.3 micrometers vs. 0.81-0.87 micrometers), their output spectrum is wider by a factor of about 1.7. The large spectrum width of LEDs causes higher fiber dispersion, considerably limiting their bit rate-distance product (a common measure of usefulness). LEDs are suitable primarily for local-area-network applications with bit rates of 10-100 Mbit/s and transmission distances of a few kilometers. LEDs have also been developed that use several quantum wells to emit light at different wavelengths over a broad spectrum, and are currently in use for local-area WDM networks.

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, allowing high coupling efficiency (~50 %) into single-mode fiber. The narrow spectral width also allows for high bit rates since it reduces the effect of chromatic dispersion. 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 electroabsorption modulator or Mach-Zehnder interferometer. External modulation increases the achievable link distance by eliminating laser chirp, which broadens the linewidth of directly-modulated lasers, increasing the chromatic dispersion in the fiber.

Fiber

Optical fiber consists of a core, cladding, and a protective outer coating, which guides light along the core by total internal reflection. The core, and the higher-refractive-index cladding, are typically made of high-quality silica glass, though they can both be made of plastic as well. An optical fiber can break if bent too sharply. Due to the microscopic precision required to align the fiber cores, connecting two optical fibers, whether done by fusion splicing or mechanical splicing, requires special skills and interconnection technology.[1].

Two main categories of optical fiber used in fiber optic communications are multi-mode optical fiber and single-mode optical fiber. Multimode fiber has a larger core (≥ 50 micrometres), allowing less precise, cheaper transmitters and receivers to connect to it as well as cheaper connectors. However, multi-mode fiber introduces multimode distortion which often limits the bandwidth and length of the link. Furthermore, because of its higher dopant content, multimode fiber is usually more expensive and exhibits higher attenuation. Single-mode fiber's smaller core (<10 micrometres) necessitates more expensive components and interconnection methods, but allows much longer, higher-performance links.

In order to package fiber into a commercially-viable product, it is protectively-coated, typically by using ultraviolet (UV) light-cured acrylate polymers, and assembled into a fiber-optic cable. It can then be laid in the ground, run through a building or deployed aerially in a manner similar to copper cable. Once deployed, such cables require substantially less maintenance than copper cable. [1]

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 20 km, 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 photodetector that converts light into electricity through the photoelectric effect. The photodetector 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) photodetectors 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 transimpedance 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.

Bandwidth-distance product

Because the effect of dispersion increases with the length of the fiber, a fiber transmission system is often characterized by its *bandwidth-distance product*, often expressed in units of MHz×km. This value is a product of bandwidth and distance because there is a trade off between the bandwidth of the signal and the distance it can be carried. For example, a common multimode fiber with bandwidth-distance product of 500 MHz×km could carry a 500 MHz signal for 1 km or a 1000 MHz signal for 0.5 km.

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 requiring higher bandwidth or spanning longer distances than electrical cabling can accommodate. 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 because of its

- Lower material cost, where large quantities are not required.
- Lower cost of transmitters and receivers.
- Ease of splicing.
- Capability to carry electrical power as well as signals.

Because of these benefits of electrical transmission, optical communication is not common in short box-to-box, backplane, or chip-to-chip applications; however, optical systems on those scales have been demonstrated in the laboratory.

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

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

http://www.smartcomputing.com/articles/archive/R0501/04r01/04R01.pdf?guid=

How Fiber Optics Work

Wavelength Division Multiplexing

Simply put, **fiber optics** is the use of light pulses to transmit data through thin strands of glass or plastic. However, there's nothing simple about the advantages it provides over wire cable, once the most common method used to transmit data. Optical fiber carries more data at a faster pace, is smaller and easier to install, and is less susceptible to interference, making it more secure.
Commercial installation of optical fiber didn't really begin until the late 1970s. It has since nearly replaced wire cable as the primary means for long-distance communication. A single optical fiber cable less than an inch thick can carry hundreds of thousands of voice conversations, with transmission rates for commercial optical fiber ranging from 2.5Gbps (gigabits per second) to 10Gbps.

Also, its signals can travel more than 60 miles before needing regeneration. Electronic signals, on the other hand, need to be regenerated about every mile. In a typical configuration, a fiber-optic cable connects to a transmitter, which connects to a wire cable. Electronic signals are converted into light pulses that beam into the fiber's core with an LED (light-emitting diode) or laser.

The core and surrounding cladding are made of pure glass or plastic. The highly reflective surface produced by the interface causes light to constantly reflect toward the center. This is known as **total internal reflection**. The two types of fiber commonly used are single mode and multimode. **Singlemode** has a narrower core and carries one light mode at a time. It is less susceptible to distortion, so signals travel farther. **Multimode** carries hundreds of modes at once, but signals weaken more quickly.

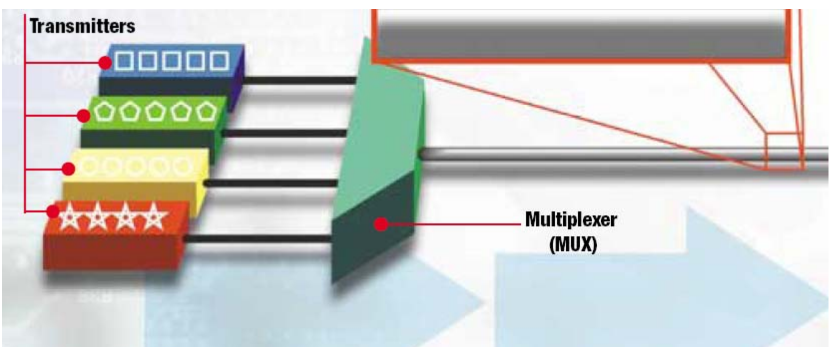
The illustration below demonstrates WDM (wavelength division multiplexing), a technology that allows multiple wavelengths of light to travel simultaneously on a single optical fiber, with each wavelength carrying 2.5Gbps or more of data. The technology enables each wavelength to use a slightly different color so they don't interfere with one another. The process begins with various transmitters equipped with lasers or LEDS funneling data into an optical fiber in the form of light pulses. A multiplexer groups the wavelengths together and passes them through a single fiber until they reach another multiplexer, which separates the group and passes the individual wavelengths to receivers that convert the light back into electronic signals.

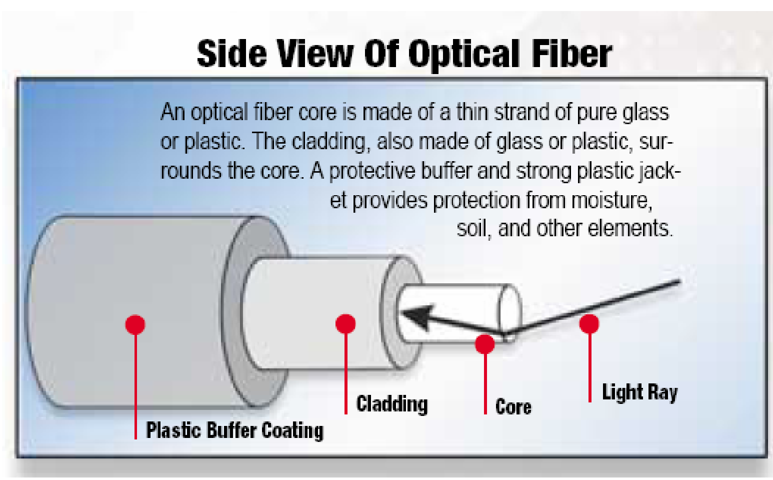
Multiplexer
(MUX)
Transmitters

This magnified view illustrates several wavelengths of a light traveling simultaneously on a single fiber using wavelength division multiplexing technology.

Compiled by Blaine Flamig
Graphics & Design by Jason Codr

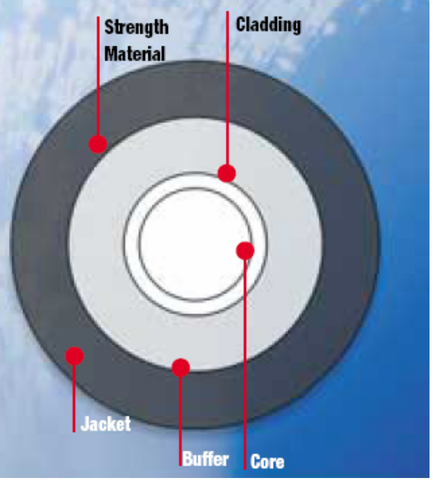
Strength
Material





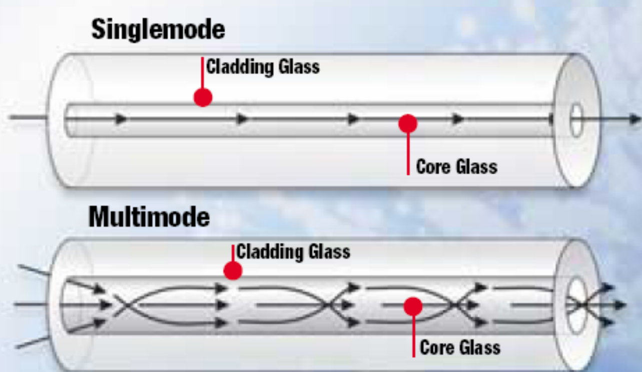
Front View Of Optical Fiber

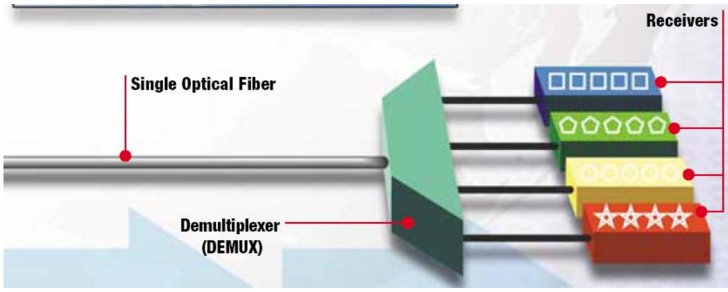
This diagram shows a front view of an optical fiber. A singlemode fiber has a core typically measuring 8 to 10 microns. (A micron equals one-millionth of a meter.) A multimode core usually measures 50 to 62.5 microns. Together, the core and cladding are approximately 125 microns, which is about the same size as a strand of human hair. The inclusion of the protective jacket gives an optical fiber a diameter of 250 to 900 microns.



Singlemode vs. Multimode

Singlemode fibers, which transmit only one mode of light at a time, are used for long-distance transmission, such as telecommunications and WANs (wide-area networks). Multimode fibers carry hundreds of modes of light at once and are used for short-distance transmissions, such as LANs (local-area networks).




Receivers
Single Optical Fiber
Demultiplexer
(DEMUX)