FIBER OPTIC CABLE

THEORY AND CONSTRUCTION

The major benefit of fiber optics over its alternatives is superior transmission capacity, or bandwidth. One optical fiber can carry almost 375 times as much voice and data as high capacity, high-speed T-1 communication lines. Fibers of ultrapure glass carry voice, video, and data signals faster than electron-based copper or coaxial cabling. AT&T Bell Laboratories has tested a system that enables transmission at 4 billion bits per second.

Fiber cabling also surpasses conventional electronic wiring systems for transmitting signals over long distances. Signals on electronic cabling must be re-transmitted every mile or so by repeaters. Fiber optic links can carry unrepeated signals great distances. Experimental systems have sent signals via fiber up to 125 miles without the aid of repeaters.

Another advantage of optical fiber is phenomenally low error rates. Typically, only one in 100 billion bits of information transmitted by fiber optic cabling is faulty as compared with one in 10 billion bits for the next best medium, broadband coaxial cabling.

Fiber optic transmission is not sensitive to electromagnetic interference as are electron based systems.

Fiber optic cabling has the advantage over conventional circuitry for protecting sensitive information against electronic meddling. Even without direct physical contact, it's possible for monitoring devices to pick up signals from the electromagnetic field that surrounds coaxial or copper cabling. Light signals cannot be tapped electromagnetically and fiber optic cabling is virtually impossible to tap.

SYSTEMS COMPONENTS

Like any communication system, a fiber optic link includes a transmitter, a transmission medium, and a receiver. Fiber optic links are designed to accept input and produce output in standard electronic formats but inside the fiber optic system, the signal is transmitted in the form of light.

The light source within the transmitter is a semi-conductor laser or light-emitting diode. Electronic circuits within the transmitter convert the input signal into a bias current which drives the laser or LED. When current exceeds a threshold value, which depends on the individual device, the semi-conductor junction emits light with intensity dependent on how much larger the current is than the threshold level. The result is a straightforward amplitude modulation applied by the bias current to a carrier wave with frequency around 300,000 gigahertz. Laboratory transmitters based on semi-conductor lasers have operated in the gigahertz or gigabits-per-second range, but only a hand full of commercial systems operate above 100 megahertz or 100 megabits-per-second. LED's generally operate at lower speeds than lasers.

At the end of the fiber, the light from the laser or LED is changed back into an electrical signal by a photo detector, a semi-conductor device which generates a current when light illuminates a junction. A variety of photo detectors are available, with wavelength response dependent on composition of the sem-conductor, and response speed and amplitude dependent on device structure. Electrical output of a photo detector generally requires amplification and often needs some form of "cleaning up" before the signal can be passed on by the fiber optic system. This processing and amplification is the job of the receiver electronics. Fiber optic light sources and detectors can operate in either analog or digital mode and over a range of speeds.

Light is carried from the transmitter to the receiver through an optical fiber, which confines light to a central core, described in more detail below. Because a waveguiding effect is involved, optical fibers are sometimes called optical waveguides, a term which sometimes is applied to thin-film planar waveguides.

In telecommunication systems, the ends of separate fibers are usually spliced together permanently, either by melting ("fusion" splicing) or by gluing with epoxy. In many other fiber optic system, connectors are factory-mounted on fiber ends, then mated together in the field to join the fibers. Splices offer lower loss and are inexpensive, but connectors are needed when the system configuration is subject to change.

FUNDAMENTAL PRINCIPLE

The fundamental principle underlying the operation of optical fibers is total internal reflection. Internal reflection may occur when light traveling in a material strikes the boundary of another material with a lower refractive index. The angle at which internal reflection will occur is dependent upon the difference of refractive indices of the two materials.

Optical fibers are designed with a circular core region surrounded by a concentric cladding layer with the index of refraction of the core slightly higher than that of the cladding. The refractive index difference determines the acceptance angle of the fiber (numerical aperture). Optical energy entering the fiber core within this acceptance angle will propagate within the core region. The fibers employ a glass core and glass cladding with various materials added to provide the required refractive index variation.

FIBER TYPES

There are three basic types of fiber which can be used in communication systems: Multi-mode step-index, multi-mode graded-index, and single-mode.

MULTI-MODE STEP-INDEX:
The light carrying core of this fiber is surrounded by a cladding of glass with a lower refractive index. There is a discontinuity of "step" in the refractive index at the core-cadding boundary, hence the name. If light in the core hits this boundary at a glancing angle, it is totally reflected back into the core. This mechanism, known as total internal reflection, is what guides the light along the core of a step-index fiber.

In multi-mode fibers, the core is typically tens of micrometers to one millimeter in diameter. Light rays can take many different paths through such cores and these paths may differ significantly in length. The difference in path length causes pulses of light to spread out as they travel along a fiber and, thereby, reduce the bandwidth of the fiber. The pulse-spreading effect gets worse as core diameter increases, leading to a trade-off with light-collection capability and ease of connection, both of which increase with core diameter.

SINGLE-MODE:
If the core diameter of step-index fiber is reduced to a few micrometers, the number of different paths a light wave can take is effectively reduced to one. This is best seen from the standpoint of waveguide theory, which indicates that such a fiber can support only one mode; hence, the name single-mode. This effectively eliminates pulse dispersion due to path-length differences and as a result, single-mode fibers have the broadest bandwidth of any type. In practice, other effects limit bandwidth, but only become significant at frequencies well into the gigahertz range. Unfortunately, the small core diameter of single-mode fibers makes it hard to transfer light into such fibers from light sources or other types of fiber, a very serious problem in practical communication systems.

MULTI-MODE GRADED-INDEX:
It's possible to combine broad bandwidth with good light-collecting capability by using a different type of fiber structure -- the graded-index fiber. In this type, the boundary between core and cladding is not abrupt but gradual, so the change in refractive index with distance from the center of the fiber is not a sharp step but a gradual slope. Light trying to pass from the core through this graded region at a low enough angle is gradually bent back toward the core rather than abruptly reflected. If the refractive index profile is properly adjusted, light rays traveling different paths through a graded-index fiber will travel nearly the same distance, minimizing pulse spreading and increasing bandwidth. Of necessity, the manufacturing of graded-index fibers is a somewhat more complex task than production of step-index fibers, but graded-index fiber has major advantages and is mass-producible. Graded-index fiber is used in virtually all long-distance fiber optic links for commercial telecommunications.

CABLE CONSTRUCTION CONSIDERATIONS

If fibers are not stressed, their mechanical and optical properties remain unchanged for typical lifetimes of 20 to 40 years, even in the presence of humidity, water, and strongly acid and basic chemicals.

Fibers that are stressed due to tension or sharp bending (macro bending) are fatigued, exhibit loss of strength and may fail, even when the stress is well below screen test levels used at the fiber manufacturing stage. In addition to stress affecting fiber life, stress upon the fiber also can produce micro bending, or microscopic fiber bends, which will increase the signal loss of the fiber.

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The fiber sensitivity to micro bending is a function of the core-cladding diameter ratio, the difference between core and cladding and the primary coating. In order to eliminate added loss due to micro bending, the cable structure must isolate the fiber from stress due to both environmental effects, such as temperature and physical properties such as bending, and residual stress due to installation conditions. The cable structure also must restrain the minimum bend radius of the fiber since micro bending which occurs below a minimum bend radius will also induce added fiber attenuation.

Traditionally, cable designs have been classified as either tight or loose buffer designs. The design type is differentiated by the protective coating or buffer that is used to facilitate fiber handling during the cabling process.

Tight buffer designs are characterized by application of one or two layers of protective plastic over the primary fiber coating. This may be on an individual fiber basis or in a ribbon structure. The former normally yields a cabling element with an outer diameter of 0.9 to 1 mm and is tightly contained within the cable structure. In ribbon design several fibers, typically 12, are sandwiched in parallel between two tape layers but the ribbon or layers of ribbons normally are allowed to float within the cable structure.

The loose structure is characterized by the fiber or fibers being placed in a cavity whose inner dimensions are much larger than that of the outer diameter of the coated fiber. Common types are slotted core or loose tube design. A variation on the loose tube design is the filled loose tube. This technique uses a viscous fluid which allows for fiber movement and excludes the presence of water.

As a general rule, when optimum environmentally stable transmission characteristics, especially under continuous mechanical stress, are specified, the filled loose buffer will be preferred. If, however, simple and robust designs with small numbers of fibers are required, the tight buffer may be advantageous.

Typically tight buffer designs are more sensitive to low temperature because of the relative large amount of plastic in intimate contact with the fiber. Since the coefficient of thermal expansion for plastic and glass are very dissimilar, the contraction forces at low temperature of the fiber coating can cause unacceptable added loss. Tight buffering also is more sensitive to added loss during buffering and subsequent cabling operations.

In order to minimize cable elongation and contraction characteristics, structural members are included in many cable designs. The structural center member is normally steel or epoxy fiberglass, as a core foundation, around which the buffered fibers are stranded and act as an anti buckling element. Typically, a layer of Kelvar® is placed over the cable core to serve as the primary cable load-bearing element.

The table below describes representative cable performance and should be used as a guideline for system design.

TYPICAL CABLE TRANSMISSION CHARACTERISTICS			
Operating Wavelength (nanometers)	Attenuation (dB / km)	Bandwidth (MHz / km)	Distance between repeaters for 90 Mbps system (km)
850	2.8 - 4.5	200 - 1,000	12
1,300	0.9 - 2.5	200 - 1,300	22
850 /1,300	2.8 / 1.5 - 4.5 / 3.0	200 - 800	10* / 12 / 14

TRANSMISSION CONSIDERATIONS

Bandwidth, or information carrying capacity, and attenuation, or loss of power, are the two primary properties of the transmission medium that impact the performance of a fiber optic communications system. Fiber bandwidth is specified normalized to a 1 km length and expressed in units of megahertz per kilometer. Optical characteristics for typical constructions are:

OPTICAL CHARACTERISTICS					
Construction	Glass Type	Code (X)	Operating Wavelength (nanometers)	Minimum Bandwidth (MHz / km)	Maximum Attenuation (db / km)
Loose tube	50 / 125 multi-mode	1	850 / 1,300	400 / 400	3.0 1 / 1.0
Loose tube	62.5 / 125 multi-mode	2	850 / 1,300	160 / 500	3.25 / 1.0
Loose tube	8 / 125 single-mode	3	1,310 / 1,550		0.45 / 0.35
Tight buffered & micro-loose tube	50 / 125 multi-mode	1	850 / 1,300	400 / 400	3.50 / 1.25
Tight buffered & micro-loose tube	62.5 / 125 multi-mode	2	850 / 1,300	160 / 500	3.50 / 1.25
Tight buffered & micro-loose tube	8 / 125 single-mode	3	1,310 / 1,550		0.80 / 0.5

*With wavelength division multiplexing.

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