Fiber Optic Technology 101

Principles and Advantages

When is fiber the ideal choice
For your network?

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Introduction

Fiber optic cable is one of the fastest-growing transmission mediums for both new cabling installations and upgrades, including backbone, horizontal, and even desktop applications. It works very well in applications that need high bandwidth, long distances, and complete immunity to electrical interference. That makes it ideal for high-data-rate systems such as Gigabit Ethernet, multi-media, Fibre Channel, or any other network that requires the transfer of large, bandwidth-consuming data files, particularly over long distances.

Fiber optic links offer far greater distances than copper links do. Conventional electrical data signals are converted into a modulated light beam, introduced into the fiber and transported via a very small diameter glass or plastic fiber to a receiver that converts the light back into electrical signals.

Fiber Optic Cable Construction

Because it's usually made of glass, fiber optic cable cannot withstand sharp bending or longitudinal stress—even though it seems quite flexible. Therefore, when fiber is placed inside complete cables, special construction techniques are used to allow the fiber to move freely within a tube. Usually fiber optic cables contain several fibers, a strong central strength member, and one or more metal sheaths for mechanical protection. Some cables also include copper pairs for auxiliary applications.

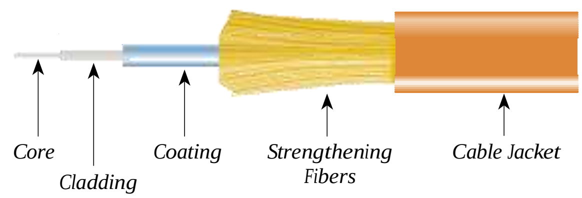

Figure 1. Fiber Optic Cable Construction

Core —This is the physical medium that transports optical data signals from an attached light source to a receiving device. The core is a single continuous strand of glass or plastic that's measured in microns (µm) by the size of its outer diameter. The larger the core, the more light the cable can carry. All fiber optic cable is sized according to its core's outer diameter.

Cladding—This is the thin layer that surrounds the fiber core and serves as a boundary that contains the light waves and causes the refraction, enabling data to travel throughout the length of the fiber segment.

Coating—This is a layer of plastic that surrounds the core and cladding to reinforce and protect the fiber core. Coatings are measured in microns and can range from 250 to 900 microns.

Strengthening fibers —These components help protect the core against crushing forces and excessive tension during installation. This material is generally Kevlar® yarn strands within the cable jacket.

Cable jacket—This is the outer layer of any cable. Most fiber optic cables have an orange jacket although some types can have black, yellow, aqua, or other color jackets. Various colors can be used to designate different applications within a network.

Fiber Optic Principles

Fiber's ability to carry light signals, with very low losses, is based on some fundamental physics associated with the refraction and reflection of light. Whenever a ray of light passes from one transparent medium to another, the light is affected by the interface between the two materials. This occurs because of the difference in speeds that the light can travel through different materials. Each material can be described in terms of its refractive index, which is the ratio of the speed of light in the material to its speed in free space. The relationship between these two refractive indices determines the critical angle of the interface between the two materials.

Three things can happen when a ray of light hits an interface. Each depends on the angle of incidence of the ray of light with the interface. If the angle of incidence is less than the critical angle, the light ray will refract, bending toward the material with the higher refractive index. If the angle of incidence is exactly equal to the critical angles, the ray of light will travel along the surface of the interface. If the angle of incidence is greater than the critical angle, the ray of light will reflect.

The refractive index of a vacuum is considered to be 1. Often, we consider the refractive index of air also to be 1 (although it is actually slightly higher). The refractive index of water is typically about 1.33. Glass, which is used in fiber cabling, has a refractive index in the range of 1.5, a value that can be manipulated by controlling the composition of the glass itself.

Fiber Optic Characteristics

Optical fibers allow data signals to propagate through them by ensuring that the light signal enters the fiber at an angle greater than the critical angle of the interface between two types of glass. The center core is composed of very pure glass with a refractive index of 1.5. Core dimensions are usually in the range of 8 to 62.5 µm. The surrounding glass, called cladding, is a slightly less pure glass with a refractive index of 1.45. The diameter of the core and cladding together is in the range of 125 to 440 µm. Surrounding the cladding is a coating, strengthening fibers, and a jacket.

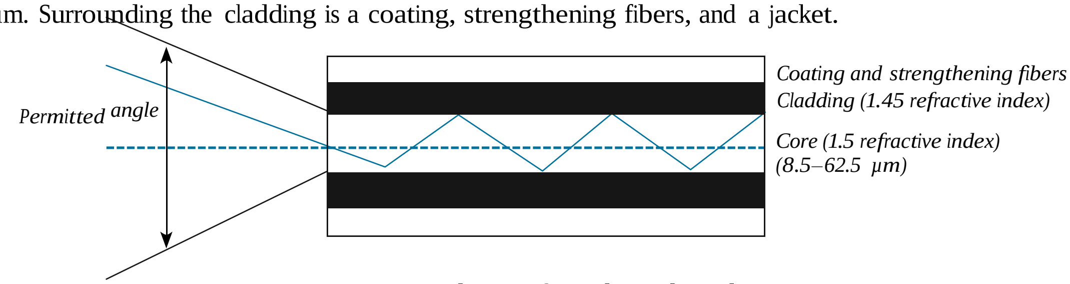

Figure 2. Light Traveling Through a Fiber

When light is introduced into the end of an optical fiber, any ray of light that hits the end of the fiber at an angle greater than the critical angle will propagate through the fiber. Each time it hits the interface between the core and the cladding it is reflected back into the fiber. The angle of acceptance for the fiber is determined by the critical angle of the interface. If this angle is rotated, a cone is generated. Any light falling on the end of the fiber within this cone of acceptance will travel through the fiber. Once the light is inside the fiber, it "bounces" through the core, reflecting inward each time it hits the interface.

Figure 2 illustrates how light rays travel through the fiber, reflecting off the interface. If the physical dimensions of the core are relatively large, individual rays of light will enter at slightly different angles and will reflect at different angles. Because they travel different paths through the fiber, the distance they travel also varies. As a result, they arrive at the receiver at different times. A pulse signal sent through the fiber will emerge wider than it was sent, deteriorating the quality of the signal. This is called modal dispersion.

Another effect that causes deterioration of the signal is chromatic dispersion. Chromatic dispersion is caused by light rays of different wavelengths traveling at different speeds through the fiber. When a series of pulses is sent through the fiber, modal and chromatic dispersion can eventually cause the pulse to merge into one long pulse and the data signal is lost.

Another characteristic of optical fiber is attenuation. Although the glass used in the core of optical fiber is extremely pure, it is not perfect. As a result, light can be absorbed within the cable. Other signal losses include bending and scattering losses as well as losses from poor connections. Connection losses can be caused by misalignment of the ends of the fiber or end surfaces that are not properly polished.

Fiber Optic Ethernet Standards

10BASE-FL — 10-Mbps Ethernet over multimode fiber.

100BASE-SX — 100-Mbps Ethernet over 850-nm multimode fiber. Maximum length is 300 meters. Longer distances are possible with single-mode fiber. Backwards compatible with 10BASE-FL.

100BASE-FX — 100-Mbps Ethernet (Fast Ethernet) over 1300-nm multimode fiber. Maximum length is 400 meters for half-duplex connections (to ensure collisions are detected) or 2 kilometers for full-duplex. Longer distances are possible with single-mode fiber. Not backwards compatible with 10BASE-FL.

100BASE-BX — 100-Mbps Ethernet over single-mode fiber. Unlike 100BASE-FX, which uses a pair of fibers, 100BASE-BX uses a single strand of fiber and wavelength-division multiplexing, which splits the signal into transmit and receive wavelengths. The two wavelengths used for transmit and receive are either 1310 and 1550 nm or 1310 and 1490 nm. Distance is up to 10, 20, or 40 km.

1000BASE-SX — 1-Gbps Ethernet (Gigabit Ethernet) over 850-nm multimode fiber up to 550 meters, depending on the what micron cable is used.

1000BASE-LX — 1-Gbps Ethernet over 1300-nm multimode fiber up to 550 meters. Optimized for longer distances (up to 10 kilometers) over single-mode fiber.

1000BASE-LH — 1-Gbps Ethernet over single-mode fiber up to 100 kilometers.

10GBASE-SR — 10-Gbps Ethernet (10-Gigabit Ethernet) over 850-nm multimode fiber. It has a range between 26 and 82 meters, depending on whether you're using 50- or 62.5 micron cable. It also supports 300 meters over 2000 MHz/km multimode fiber.

10GBASE-LX4 — 10-Gbps Ethernet over 1300-nm multimode fiber. Uses wavelength-division multiplexing to support up to 300 meters over multimode cabling. Also supports 10 kilometers over single-mode fiber.

Buyer's Guide | Multimode Fiber Types and Standards

Industry Standards			Fiber Type (µm)	Attenuation[4] - Typical Cabled Max. (dB/km)		Bandwidth (MHz-km)		
						Overfilled Launch (OFL)		Effective Modal Bandwidth (EMB) (also known as Laser BW)
ISO/IEC 11801	IEC 60793-2-10	TIA/EIA		850 nm	1300 nm	850 nm	1300 nm	850 nm
OM1[1]	A1b	492-AAAA	62.5/125	3.5	1.5	200	500	—
OM2[2]	A1a.1	492-AAAB	50/125	3.5	1.5	500	500	—
OM3	A1a.2	492-AAAC	50/125	3.5	1.5	1500	500	2000
OM4[3]	A1a.3	492-AAAD	50/125	3.5	1.5	3500	500	4700

ISO/IEC 11801 "Generic Cabling for Customer Premises"
IEC 60793-2-10 "Product Specifications - Sectional Specification for Category A1 Multimode Fibers"
TIA/EIA-492-AAAx "Detail Specification for Class 1a Graded-Index Multimode Optical Fibers"
(1) OM1 is typically a 62.5-um fiber, but can also be a 50-µm fiber.
(2) OM2 is typically a 50-um fiber, but can also be a 62.5-µm fiber.
(3) OM4 was ratified by the IEEE in June 2010 and is the 802.ba 40G/100G Ethernet standard. It's for use up to 1000 meters for 1-GbE, 550 meters for 10-GbE, and 150 meters for 40-GbE and 100-GbE networks.
(4) The ISO/IEC 11801 standard stipulates maximum cable attenuation. The IEC and TIA fiber standards call for lower (and varied) bare fiber attenuation.

Multimode vs. Single-Mode Cable

Multimode, 50- and 62.5-micron cable

Multimode cable has a large-diameter core and multiple pathways of light. The two most commnon are 50 micron and 62.5 micron.

Multimode fiber optic cable can be used for most general data and voice fiber applications, such as bringing fiber to the desktop, adding segments to an existing network, and in smaller applications such as alarm systems. Both 50- and 62.5-micron cable feature the same cladding diameter of 125 microns, but 50-micron fiber cable features a smaller core (the light-carrying portion of the fiber). Also, both also use either LED or laser light sources.

Buyer's Guide | Fiber Performance Standards

Fiber Type	Wavelength	Attenuation (dB/km) Max.	Bandwidth (MHz/km)
Multimode			
50-/125-Micron	850 nm	3.5	500
	1300 nm	1.5	500
62.5-/125-Micron	850 nm	3.5	160
	1300 nm	1.5	500
Single-Mode 8–10-Micron			
Premises	1310 nm	1.0	—
	1550 nm	1.0	—
Outside Plant	1310 nm	0.5	—
	1550 nm	0.5	—

Although both can be used in the same way, 50-micron cable is recommended for premise applications (backbone, horizontal, and intrabuilding connections) and should be considered for any new construction and installations. The big difference between the two is that 50-micron cable provides longer link lengths and/or higher speeds, particularly in the 850-nm wavelength.

Single-mode, 8–10-micron cable

Single-mode cable has a small 8–10-micron glass core and only one pathway of light. With only a single wavelength of light passing through its core, single-mode cable realigns the light toward the center of the core instead of simply bouncing it off the edge of the core as multimode does.

Single-mode cable provides 50 times more distance than multimode cable does. Consequently, single-mode cable is typically used in high-bandwidth applications and in long-haul network connections spread out over extended areas, including cable television and campus backbone applications. Telcos use it for connections between switching offices. Single-mode cable also provides higher bandwidth, so you can use a pair of single-mode fiber strands full-duplex for up to twice the throughput of multimode fiber.

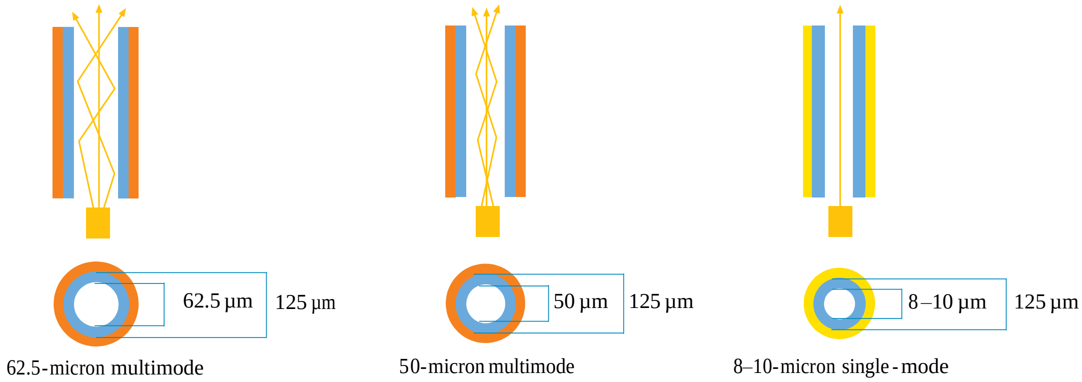

Figure 3. Types of Fiber

Simplex vs. duplex Patch cables

Multimode and single-mode patch cables can be simplex or duplex.

Simplex has one fiber, while duplex zipcord has two fibers joined with a thin web. Simplex (also known as single strand) and duplex zipcord cables are tight-buffered and jacketed, with Kevlar strength members.

Because simplex fiber optic cable consists of only one fiber link, you should use it for applications that only require one-way data transfer. For instance, an interstate trucking scale that sends the wieght of the truck to a monitoring station or an oil line monitor that sends data about oil flow to a central location.

Use duplex multimode or single-mode fiber optic cable for applications that require simultaneous, bidirectional data transfer. Workstations, fiber switches and servers, Ethernet switches, backbone ports, and similar hardware require duplex cable.

PVC (Riser) vs. Plenum-Rated

PVC cable (also called riser-rated cable even though not all PVC cable is riser-rated) features an outer polyvinyl chloride jacket that gives off toxic fumes when it burns. It can be used for horizontal and vertical runs, but only if the building features a contained ventilation system. Plenum can replace riser, but riser cannot be used in plenum spaces.

“Riser-rated” means that the jacket contains PVC. The cable carries a CMR (communications riser) rating and is not for use in plenums.

Plenum cable has a special coating, such as Teflon® FEP, which doesn’t emit toxic fumes when it burns. A plenum is a space within the building designed for the movement of environmental air. In most office buildings, the space above the ceiling is used for the HVAC air return. If cable goes through that space, it must be “plenum-rated.”

Distribution-Style vs. Breakout-Style

Distribution-style cables have several tight-buffered fibers bundled under the same jacket with Kevlar or fiberglass rod reinforcement. These cables are small in size and are used for short, dry conduit runs, in either riser or plenum applications. The fibers can be directly terminated, but because the fibers are not individually reinforced, these cables need to be broken out with a “breakout box” or terminated inside a patch panel or junction box.

Breakout-style cables are made of several simplex cables bundled together, making a strong design that is larger than distribution cables. Breakout cables are suitable for conduit runs and riser and plenum applications.

Indoor/Outdoor Cable

Indoor/outdoor cable uses dry-block technology to seal ruptures against moisture seepage and gel-filled buffer tubes to halt moisture migration. Comprised of a ripcord, core binder, a flame-retardant layer, overcoat, aramid yarn, and an outer jacket, it is designed for aerial, duct, tray, and riser applications.

Interlocking Armored Cable

This fiber cable is jacketed in aluminum interlocking armor so it can be run just about anywhere in a building. Ideal for harsh environments, it is rugged and rodent resistant. No conduit is needed, so it's a labor- and money-saving alternative to using innerducts for fiber cable runs.

Outside-plant cable is used in direct burials. It delivers optimum performance in extreme conditions and is terminated within 50 feet of a building entrance. It blocks water and is rodent resistant.

Interlocking armored cable is lightweight and flexible but also extraordinarily strong. It is ideal for out-of-the-way premise links.

Laser-Optimized 10-Gigabit Cable

Laser-optimized multimode fiber cable differs from standard multimode cable because it has graded refractive index profile fiber optic cable in each assembly. This means that the refractive index of the core glass decreases toward the outer cladding, so the paths of light towards the outer edge of the fiber travel quicker than the other paths. This increase in speed equalizes the travel time for both short and long light paths, ensuring accurate information transmission and receipt over much greater distances, up to 300 meters at 10 Gbps.

Loose-Tube vs. Tight-Buffered Fiber Optic Cable

There are two styles of fiber optic cable construction: loose tube and tight buffered. Both contain some type of strengthening member, such as aramid yarn, stainless steel wire strands, or even gel-filled sleeves. But each is designed for very different environments.

Loose-tube cable is specifically designed for harsh outdoor environments. It protects the fiber core, cladding, and coating by enclosing everything within semi-rigid protective sleeves or tubes. Many loose-tube cables also have a water-resistant gel that surrounds the fibers. This gel helps protect them from moisture, which makes loose-tube cable great for harsh, high-humidity environments where water or condensation can be a problem. The gel-filled tubes can also expand and contract with temperature changes.

But gel-filled loose-tube cable is not the best choice when cable needs to be routed around multiple bends, which is often true in indoor applications. Excess cable strain can force fibers to emerge from the gel.

Tight-buffered cable, in contrast, is optimized for indoor applications. Because it's sturdier than loose-tube cable, it's best suited for moderate-length LAN/WAN connections or long indoor runs. It's easier to install, as well, because there's no messy gel to clean up and it doesn't require a fan-out kit for splicing or termination. You can install connectors directly to each fiber.

The Ferrules: Ceramic or Composite?

As a general rule, use ceramic ferrules for critical network connections such as backbone cables or for connections that will be moved frequently, like those in wiring closets. Ceramic ferrules are more precisely molded and fit closer to the fiber, which gives the fiber optic cables a lower optical loss.

Use composite ferrules for connections that are less critical to the network's overall operation and less frequently moved. Like their ceramic counterparts, composite ferrules are characterized by low loss, good quality, and a long life. However, they are not as precisely molded and slightly easier to damage, so they aren't as well-suited for critical connections.

Signal Sources and Detectors

To use fiber optic cables for communications, electrical signals must be converted to light, transmitted, received, and converted back from light to electrical signals. This requires optical sources and detectors that can operate at the data rates of the communications system.

There are two main categories of optical signal sources—light emitting diodes and infrared laser diodes.

Light emitting diodes (Leds) are the lower-cost, lower-performance source. They're used in applications where lower data rates and/or shorter distances are acceptable. Infrared laser diodes operate at much higher speeds, dissipate higher power levels, and require temperature compensation or control to maintain specified performance levels. They are also more costly.

Signal detectors also fall into two main categories—PIN photodiodes and avalanche photodiodes.

Similar to sources, the two types provide much different cost/performance ratios. PIN photodiodes are more commonly used, especially in less stringent applications. Avalanche photodiodes, on the other hand, are very sensitive and can be used where longer distances and higher data rates are involved.

Splicing and Terminating Optical Fibers

In practical situations, fiber optic cables exhibit signal power losses based on both the fiber and connections from the fiber to sensors or other fiber segments. Typically fiber losses run at about 10 decibels (dB) per kilometer.

Whenever a fiber must be terminated, the goal is to produce a perfectly transparent end to the fiber. The end-face should be square, clear, and physically mated to the receiving optical device. In some cases, cables are permanently joined by splicing or gluing the ends of the fiber together. Others mechanically align the fibers and use a transparent gel to couple the ends of the fiber together.

Early fiber optic connections involved cutting the fiber, epoxying a special connector, and polishing the end of the fiber. This operation required special tools and testing equipment to ensure a good connection. While this technique is still used, devices used to cleave, align, and join fibers have been improved and simplified. Connection losses vary, depending on the type of connection, but typically range from 0.2 to 1 dB.

Fiber connectors.

The ST® connector, which uses a bayonet locking system, is the most common connector.

The SC connector features a molded body and a push-pull locking system.

The LC connector, with a small-form-factor connector, features a ceramic ferrule and looks like a mini SC connector.

The MT-RJ connector, a small-form RJ-style connector, features a molded body and uses cleave-and-leave splicing.

The VF-45™ connector is another small-form-factor connector. It uses a unique "V-groove" design.

The FC connector is a threaded connector used in high-vibration environments.

The MTO/MTP® connector is a fiber connector that uses high-fiber-count ribbon cable. It's used in high-density fiber applications.

The MU connector resembles the larger SC connector, but it's much smaller. It uses a simple push-pull latching connection. Use it in high-density applications.

Planning a Fiber Optic Link

The most important consideration in planning a fiber optic link is the power budget specification of the devices being connected. This value tells you the amount of loss in dB that can be present in the link between the two devices before the units fail to perform properly. This value will include inline attenuation as well as connector loss.

Fiber attenuators are used with single-mode fiber optic devices and cable to filter the strength of the fiber optic signal. Depending on the type of attenuator attached to the devices at each end of the fiber optic cable, you can diminish the strength of the light signal a variable amount, measured in decibels (dB).

Why would you want to filter the strength of the fiber optic signal? Single-mode fiber is designed to carry a fiber optic signal long distances—as much as 70 kilometers (or 43.4 miles). Fiber devices send this signal with great force to ensure that the signal, and your data, arrive at the other end intact.

But when two fiber devices connected with single-mode fiber cable are close to each other, the signal may be too strong. As a result, the light signal reflects back down the fiber cable. Data can be corrupted and transmissions can be faulty. A signal that is too strong can even damage the attached equipment.

Because it's probably not feasible to move your fiber equipment farther apart, the easiest solution is to attach an attenuator to each fiber device. Just as sunglasses filter the strength of sunlight, attenuators filter the strength of the light signal transmitted along single-mode fiber cable. Within the attenuator, there's doping that reduces the strength of the signal passing through the fiber connection and minute air gaps where the two fibers meet. Fiber grooves may also be intentionally misaligned by several microns—but only enough to slow the fiber optic signal to an acceptable rate as it travels down the cable.

Before selecting an attenuator, you need to check the type of adapter on your fiber devices. Attenuators typically fit into any patch panel equipped with FC, SC, or LC adapters that contain either PC or APC contacts. In addition to the type of adapter, you also need to determine the necessary attenuation value, such as 5 or 10 dB. This value varies, depending on the strength of fiber optic signal desired.

Testing and Certifying Fiber Optic Cable

If you're accustomed to certifying copper cable, you'll be pleasantly surprised at how easy it is to certify fiber optic cable because it's immune to electrical interference. You only need to check a few measurements.

Attenuation (or decibel loss)—Measured in decibels/kilometer (dB/km), this is the decrease of signal strength as it travels through the fiber cable. Generally, attenuation problems are more common on multimode fiber optic cables.

Return loss—This is the amount of light reflected from the far end of the cable back to the source. The lower the number, the better. For example, a reading of -60 decibels is better than -20 decibels. Like attenuation, return loss is usually greater with multimode cable.

Graded refractive index—This measures how the light is sent down the fiber. This is commonly measured at wavelengths of 850 and 1300 nanometers. Compared to other operating frequencies, these two ranges yield the lowest intrinsic power loss. (NOTE: This is valid for multimode fiber only.)

Propagation delay—This is the time it takes a signal to travel from one point to another over a transmission channel.

Optical time-domain reflectometry (OTDR)—This enables you to isolate cable faults by transmitting high-frequency pulses onto a cable and examining their reflections along the cable. With OTDR, you can also determine the length of a fiber optic cable because the OTDR value includes the distance the optic signal travels.

There are many fiber optic testers on the market today. Basic fiber optic testers function by shining a light down one end of the cable. At the other end, there's a receiver calibrated to the strength of the light source. With this test, you can measure how much light is going to the other end of the cable. Generally these testers give you the results in dB lost, which you then compare to the loss budget. If the measured loss is less than the number calculated by your loss budget, your installation is good.

Newer fiber optic testers have an even broader range of capabilities. They can test both 850- and 1300-nanometer signals at the same time and can even check your cable for compliance with specific standards.

Precautions to Take When Using Fiber

A few properties particular to fiber optic cable can cause problems if you aren't careful during installation:

Intrinsic power loss—As the optic signal travels through the fiber core, the signal inevitably loses some speed through absorption, reflection, and scattering. This problem is easy to manage by making sure your splices are good and your connections are clean.

Microbending—Microbends are minute deviations in fiber caused by excessive bends, pinches, and kinks. Using cable with reinforcing fibers and other special manufacturing techniques minimizes this problem.

Connector loss—Connector loss occurs when two fiber segments are misaligned. This problem is commonly caused by poor splicing. Scratches and dirt introduced during the splicing process can also cause connector loss.

Coupling loss—Similar to connector loss, coupling loss results in reduced signal power and is from poorly terminated connector couplings. Remember to be careful and use common sense when installing fiber cable. Use clean components. Keep dirt and dust to a minimum. Don't pull the cable excessively or bend it too sharply around corners.

Advantages of Fiber Optic Cables

Greater bandwidth

Fiber provides far greater bandwidth than copper and has standardized performance up to 10 Gbps. But fiber also gives network designers future-proofing insurance with speeds up to 40 Gbps or even 100 Gbps.

Low attenuation and greater distance

Because the fiber optic signal is made of light, very little signal loss occurs during transmission, and data can move at higher speeds and greater distances. Fiber does not have the 100-meter (328-ft.) distance limitation that unshielded twisted-pair copper without a booster does. Fiber distances can range from 300 meters (984.2 ft.) to 70 kilometers (24.8 mi.), depending on the style of cable, wavelength, and network. (Fiber distances are typically measured in metric units.) Because fiber signals need less boosting than copper ones do, the cable performs better. Note than single-mode cable offers far greater distance than either 62.5- or 50-micron multimode cable.

Immunity and reliability

Fiber provides extremely reliable data transmission. It's completely immune to many environmental factors that affect copper cable. Because the core is made of glass, which is an insulator, no electric current can flow through. It's immune to electromagnetic interference and radio-frequency interference (EMI/RFI), crosstalk, impedance problems, and more. You can run fiber next to industrial equipment without worry. Fiber is also less susceptible to temperature fluctuations than copper is, and it can be submerged in water. In addition, fiber optic cable can carry more information with greater fidelity than copper wire can. That's why telephone and CATV companies are converting to fiber.

Security

Your data is safe with fiber cable. It doesn't radiate signals and is extremely difficult to tap. If the cable is tapped, it's very easy to monitor because the cable leaks light, causing the entire system to fail. If an attempt is made to break the physical security of your fiber system, you'll know it. Fiber networks also enable you to put all your electronics and hardware in one central location, instead of having wiring closets with equipment throughout the building.

Design and installation

Fiber is lightweight, thin, and more durable than copper cable. Plus, fiber optic cable has pulling specifications that are up to 10 times greater than copper cable's. Its small size makes it easier to handle, and it takes up much less space in cabling ducts. Although fiber is still more difficult to terminate than copper, advancements in connectors are making termination easier. In addition, fiber is actually easier to test than copper cable.

Migration

The proliferation and lower costs of media converters are making copper to fiber migration much easier. The converters provide seamless links and enable the use of existing hardware. Fiber can be incorporated into networks in planned upgrades. TIA/EIA-785, ratified in 2001, provides a cost-effective migration path from 10-Mbps Ethernet to 100-Mbps Fast Ethernet over fiber (100BASE-SX). An addendum to the standard eliminates limitations in transceiver designs. In addition, in June 2002, the IEEE approved a 10-Gigabit Ethernet (10-GbE) standard.

Costs

The cost for fiber cable, components, and hardware is steadily decreasing. Installation costs for fiber are higher than copper because of the skill needed for terminations, making fiber more expensive than copper in the short run, but it may actually be less expensive in the long run. Fiber typically costs less to maintain, has much less downtime, and requires less networking hardware. And fiber eliminates the need to re-cable for higher network performance.