Optical Fiber

TUTORIAL

With the cost of optical fiber technology continuing to decrease, many of today's businesses are utilizing this technology in building distribution and/or workstation applications. Optical fiber's inherent immunity to both electromagnetic interference (EMI) and radio interference (RFI), and its relatively light weight and enormous bandwidth capabilities make it ideal for voice, video and high-speed data applications.

The Evolution of Optical Fiber Transmission

The theory of using light as a transmission medium has been around for quite some time.

Back in the 1880s, Alexander Graham Bell demonstrated that light could carry voices through the air without the use of wires. Bell's Photo Phone reproduced voices by detecting variations in the amount of sunlight reaching the receiver. His theory was correct. However, it was not very practical, as any objects that got in the way of the light beam caused a disruption at the receiver.

During the 1930s, several patents surfaced that used tubing as a waveguide for light. The tubing was big and bulky, and thus impractical for use underground or in buildings.

Interest in optical fiber technology began to grow significantly in the 1950s, as a patent utilizing a two-layer glass waveguide surfaced. The principal behind the two-layer waveguide was to confine the light signal within the inner layer (core) by the use of a second layer (cladding) that would reflect the light back into the core, much like the way light is contained within water.

This development became the foundation for optical fiber transmission as we know it today. What was needed at this point was a light source capable of traveling the length of the waveguide.

In the early 1960s, a laser was first used as a light source, with tremendous results. The high cost of optical lasers, however, still prevented the practical use of optical fiber technology for communications.

In the late 1960s, it was discovered that the high loss of light in optical fiber was due to the impurities of the glass, not its intrinsic properties

It the early 1970s, engineers at Corning Glass Works refined the manufacturing process of optical fiber construction, thereby allowing for the use of lower-cost light sources, such as LEDs.

In the 1980s, optical fiber technology began to find its place as the backbone of long-distance telephone networks throughout North America.

Presently, with the advances in digital technology and the further development of standards, optical fiber technology has become an integral part of the networks of today, as they have become the foundation for tomorrow.

OPTICAL FIBER SYSTEM

There are three basic components of any optical fiber system:

- a light source or transmitter
- a receiver
- the fiber medium.

In order to understand how light travels through optical fiber cable, it is important to understand the characteristics of the different transmitters and receivers used today.

Optical Transmitters

Optical transmitters receive a modulated electrical signal and convert it into a modulated optical signal. The transmitter typically sends this pulse into the optical fiber cable as a series of light pulses (on/off).

Transmitter Types

There are two types of optical transmitters used today.

- LED
- Laser.

LED stands for Light Emitting Diode. The LED transmitter is the least expensive and is most commonly used for short-distance voice and data applications.

Laser is an abbreviation for Light Amplification by Stimulated Emission of Radiation. Lasers are more expensive than LED transmitters and are typically used in long- or short-haul, high-bandwidth applications.

Transmitter Characteristics

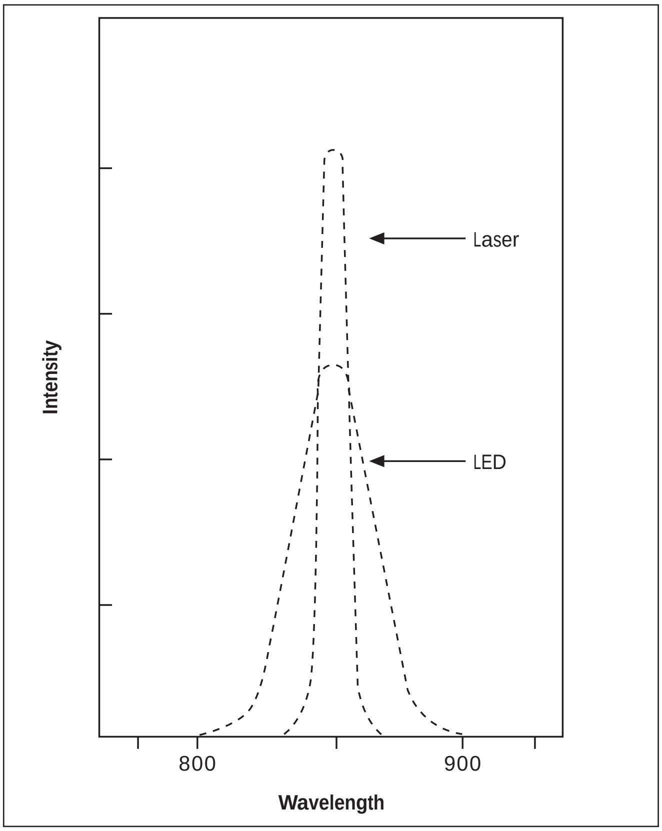
Transmitters are categorized by four basic characteristics:

- center wavelength
- spectral width
- average power
- modulation frequency.

Center Wavelength

Optical fiber does not pass all light frequencies with the same efficiency. The attenuation (resistance) of light signals is much higher for visible light than for light in the infrared region. Within the infrared region there are several wavelength bands that operate with minimal signal loss. These wavelength bands are called windows. The most common windows used are 850 nanometers (nm), 1300 nm and 1550 nm.

Spectral Width
When a transmitter emits light, the total power is distributed over a range of wavelengths on either side of the center wavelength. This range is called the spectral width. Naturally, the narrower the spectral width, the more power available for the center wavelength, the farther the light will travel.



Average Power
The average power of a transmitter is the strength of the light source during modulation. Average power is measured in milliwatts or dbm. The higher the power level, the longer the link lengths achieved.

Modulation Frequency
The modulation frequency of a transmitter is the rate at which the light source is turned on and off. The data rate of an optical fiber system is limited by this rate of change.

Optical Receivers
Optical receivers convert the received light pulse into an electrical signal. The commonly used receiver today is the PIN (photo-intrinsic-negative) type.

For proper optical fiber communication to take place, both the transmitter and receiver must be set to the same optical frequency window. Each receiver's sensitivity to light is limited to the wavelength range it was designed for. A receiver designed for the 850 nm window may not operate satisfactorily in the 1300 nm range.

There are three main characteristics to consider when selecting an optical receiver:

- sensitivity
- bit error rate (BER)
- dynamic range.

Sensitivity
The sensitivity of a receiver refers to the minimum transmitter power level required by the receiver to convert the received light pulses to an electrical signal. During this conversion, a number of errors may occur. These errors are referred to as bit errors.

Bit Error Rate (BER)
The bit error rate of a receiver is the fractional number of bit errors that are allowed to occur between the transmitter and receiver. With this in mind, if the received signal falls below the receiver's sensitivity, the BER will be high, thereby causing the communication link to fail.

Dynamic Range
If the transmitter power is too low for a given receiver's sensitivity, the BER will be high. A high BER can also occur when a transmitted signal is too high as the receiver is unable to read the distorted light pulses. The difference between the minimum and maximum level is what is referred to as a receiver's dynamic range.

Optical Fiber Cable
Optical fiber cable can be described as being a waveguide for light. It is constructed with a glass or plastic core surrounded by a refractive cladding that binds the light within the core. This construction allows optical fiber cable to carry information in the form of light. Optical fiber cables are grouped into two distinctly different categories: Multimode and Single-mode.

Optical Fiber

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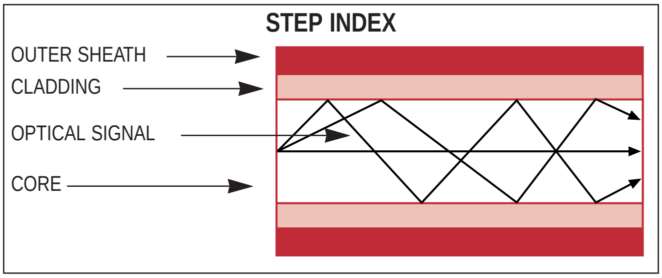
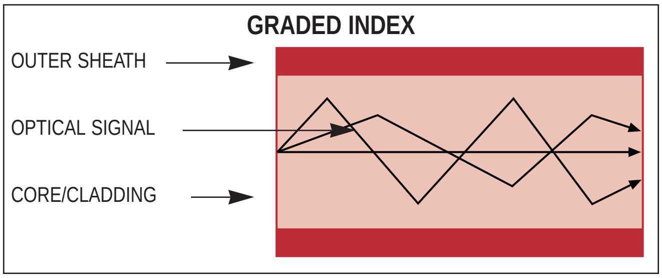
Multimode Optical Fiber

Due to the construction of Multimode fiber cable, light will take a number of paths (modes) as it travels from the transmitter to the receiver. Step index and graded index are the two most common types of Multimode fiber cable.

Step-index Multimode fiber is constructed in such a way that the core and cladding are clearly defined. The diagram below shows that as light travels along the cable, the rays of light reflect off of the cladding back into the core at various angles, resulting in varying path lengths (modes).



Graded-index Multimode fiber is constructed differently in that the index of refraction of the core varies across its diameter. The result is that the propagation delay, due to the different modes, is minimal. This creates a cable with a much higher bandwidth capability.



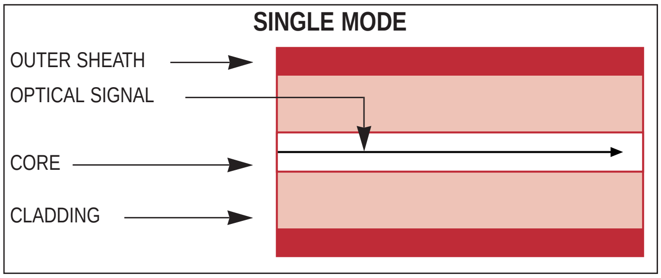
Multimode optical fiber is available in various sizes, with the most common being 50/125 µm, 62.5/125 µm and 100/140 µm, of which 62.5/125 µm is the most frequently used today. (the first number refers to the core size with the second representing the core and the cladding). The optimum transmission window for Multimode fiber is either 850 nm or 1300 nm.

Multimode Applications

Multimode systems are generally cheaper than Single-mode systems, as LED transmitters and less sophisticated receivers are used. Without the use of optical repeaters, an LED light source Multimode fiber system has a maximum (reach limit) of 5 kilometers. This (reach limit), combined with the low cost, makes Multimode systems ideal for use in short-distance voice and data applications with transmission speed requirements of 500 mbps or less.

Single-mode Optical Fiber

Single-mode fiber is also an optical waveguide. It differs from the Multimode most significantly by the extremely small core size (8-9 µm).



With the small core, the light signal can only travel in a single path (mode) from one end to the other. Single-mode fiber requires a light source that is very small and accurate, such as that of an optical Laser transmitter.

Single-mode fiber is only available in a 9/125 µm size. The optimum operating windows are 1300 mm and 1550 mm.

Single-mode Applications

The cost of a Single-mode system is much higher than that of Multimode as lasers and specialized receivers must be utilized. Without the use of optical repeaters, Single-mode systems can reach distances greater than 80 km. Data transmission rates on Single-mode systems are in the gigahertz (GHz) range, thereby making it ideal for long-distance communications.

Factors That Affect Optical Fiber System Performance

The most common factors that affect system performance are:

- attenuation
- bandwidth
- optical fiber construction.

Attenuation

Attenuation is the difference in the transmitter output power and signal level at the receiver end. Scattering and absorption are the two chief causes of attenuation.

Glass has an intrinsic property that causes it to deflect or scatter light as the light passes through it.

Absorption is caused by the impurities of the glass absorbing some of the light signal.

Macro and micro bends also affect attenuation and are caused by improper installation or termination techniques.

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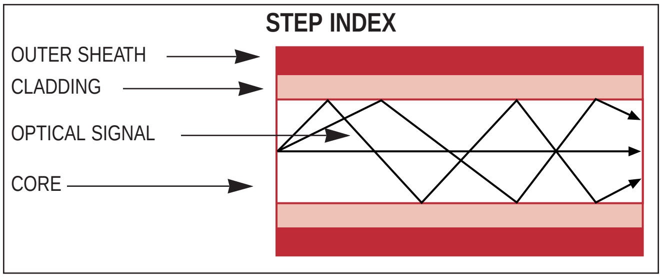

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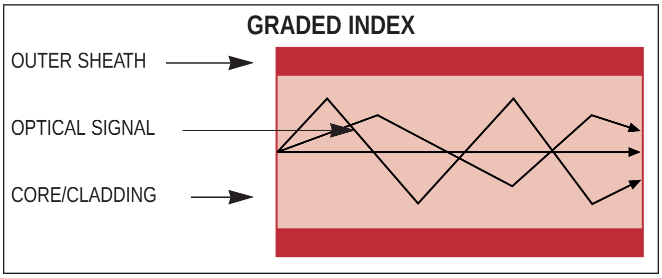

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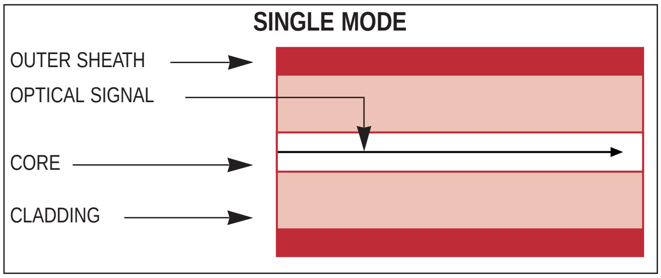

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Attenuation is measured in decibels per kilometer (dB/km). A decibel is a logarithmic measurement of power unit. A 1.0 dB loss indicates that 80% of the transmitted signal reached the far end, where a 3.0 dB loss means only 50% of the signal was received. For every three decibels of signal loss, the signal strength is reduced by 50%.

Bandwidth

Bandwidth is the information-carrying capacity of an optical waveguide. The bandwidth limitation of either Multimode or Single-mode fiber is a direct result of dispersion.

Dispersion causes the light pulse to broaden in duration as it passes along the length of optical fiber cable. There are three types of dispersion that affect bandwidth:

- modal
- chromatic
- waveguide.

In Multimode fiber, each mode of light will follow a different path through the core of the fiber as it travels along. The modes which follow the shortest paths arrive before the others, thereby causing the duration of the pulse to be extended. This effect is called modal dispersion and is greater in step-index Multimode than it is in graded-index, due to their differing constructions, as discussed earlier.

Chromatic dispersion is caused by a range of wavelengths reaching the receiver at various times. The amount of dispersion is a direct result of the light source used and its inherent spectral width. Systems using an LED as their light source are more susceptible to this type of dispersion, as its spectral width is much wider than that of a laser.

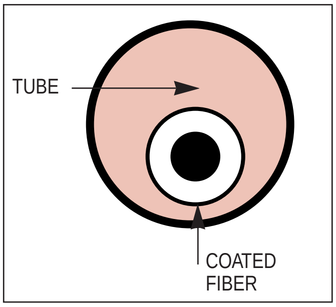
Waveguide dispersion is a direct result of light traveling in both the core and cladding material of Single-mode fiber. Waveguide dispersion is inversely proportional to wavelength, meaning that as the wavelength decreases, dispersion increases.

Bandwidth is typically expressed in a frequency/distance form (MHz/km). An optical fiber cable that has a bandwidth of 200 MHz-km can carry a 200 MHz signal up to one kilometer, or a 100 MHz signal up to 2 km or a 50 MHz signal up to 4 km, and so on.

Optical Fiber Cable Construction

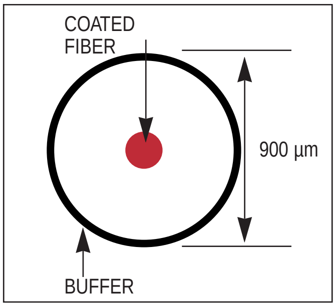
Optical fiber cables are categorized by their buffering mechanism and functionality. During the manufacturing process, a 250 µm coating is placed around the core/cladding. It is this coating that gives optical fiber the strength it needs to be used in telecommunication applications. There are two types of buffering used today: loose-tube and tight buffered cables.

Loose-tube Cables



Loose-tube buffered cables are designed so that the fiber is isolated from the cable sheath. This construction allows the optical fiber to float within a tube as the cable moves. As a result, loose-tube cables are generally used in outdoor applications where the fiber cable is subject to extreme temperature changes. Loose-tube cables are available with armored or all-dielectric construction. Armored cable is ideal for buried applications as it provides both rodent protection and crush resistance. All-dielectric cables are best suited for aerial and conduit applications as they can be placed parallel to electrical service cables without danger of induced voltages and they don't act as a path for lighting strikes into the building.

Tight Buffered Cables

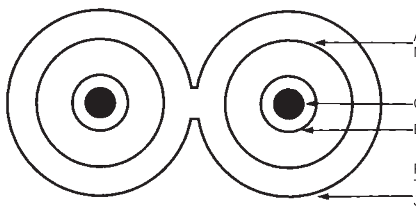


Tight buffered optical fiber cables generally have a 900 µm plastic coating applied directly to the optical fiber itself. This type of cable is more sensitive to extreme temperatures and outside forces than loose-tube cables. What make tight buffered cables desirable are their increased physical flexibility and small bend radius. They are ideal for use in indoor and interconnection applications. Tight buffered cables allow for easy field connectorization.

Optical Fiber Cable Types

There are three basic tight-buffered fiber cable types.

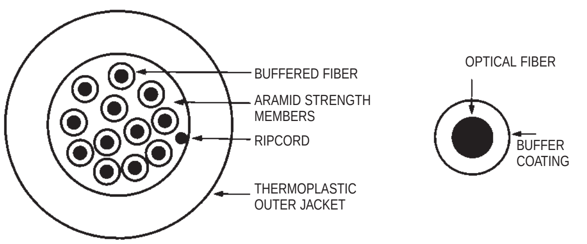
- Interconnect
- Distribution
- Breakout.



Interconnect Cables

Interconnect cables are designed for low fiber count premise applications. They are small in size and quite flexible. These characteristics makes them ideal for use in confined spaces. Their aesthetic appearance makes these cables suitable for use in open office environments where they are used to connect workstation equipment to optical fiber communication outlets. Interconnect cables are also used as optical fiber patch cords.

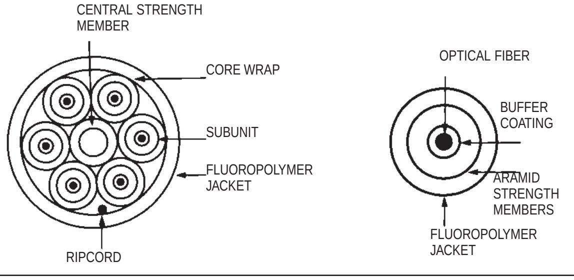
Interconnect Cable information can be found on page 6-64.



Distribution Cables

Distribution cables are designed for medium to high fiber count in-building installations and offer a high degree of flexibility for both backbone and horizontal applications. These cables are generally made with 900 µm tight-buffered optical fibers. They are available in 62.5/125 µm Multimode or 9/125 µm Single-mode or composite configurations. (Composite cable is one that has both Multimode and Single-mode fibers within the same sheath.)

Distribution Cable information can be found on page 6-52.



Breakout Cables

Breakout cables are designed for medium to high fiber count in-building, harsh-environment installations for both backbone and horizontal applications. They are made with 900 µm tight-buffered fibers and each fiber is further protected by a layer of aramid fiber yarn (kevlar) followed by a PVC jacket. Breakout cables are available in Multimode and Single-mode optical fiber configurations.

Breakout Cable information can be found on page 6-55.

Optical Fiber Connectorization

Connectors are used at patch panels or workstations to join optical fiber cables to electronic equipment, such as an intelligent wiring hub. The connector is held directly onto the optical fiber by using a mechanical or epoxy/adhesive procedure. There are a number of connectors being used today, such as: ST compatible, FC, SC and SC duplex (568SC). Which connector to use depends upon the type required by the optical equipment and fiber patch panels being used.

ANSI/TIA/EIA-568-A recommends the use of the SC connector (568SC) in premises optical fiber systems. However, the standard does recognize that there are a large number of installations terminated with ST compatible connectors and recommends that these sites continue to use the ST type for the life of the building.

When choosing a connector, a number of areas should be closely examined:

- attenuation
- return loss
- durability
- ease of field assembly.

Attenuation is the amount of optical signal that is lost as a direct result of the connection. The maximum accepted loss for a mated pair is no greater than 0.75 dB. The total loss through the cross-connect from any terminated fiber to any other terminated fiber shall not exceed 1.5 dB.

Durability refers to the connector's ability to sustain a minimum of 500 mating cycles without falling below the above mentioned specifications.

When selecting a field connector assembly, a number of criteria should be considered:

- set-up time
- special equipment required
- special training required
- cost of field consumables.

	Mechanical Connector	Epoxy Connector
Set-up time:	marginal	oven warm-up time
Equipment requirements:	fiber cleaver fiber stripper	fiber cleaver fiber stripper, oven fiber polishing kit
Training:	minimal	formal
Consumable costs:	optical connector	optical connector polishing paper epoxy syringes

There are two types of connectors available today: mechanical and epoxy. Each has its own unique requirements, yet they both achieve essentially the same results with respect to their effect on optical transmission.

Set-up time is important for projects that have a number of termination locations. The more termination locations, the longer it will take to complete the project when using an epoxy type connector, as set-up and tear-down take a lot longer than using a mechanical-type connector.

Special equipment like ovens and polishers are expensive to purchase and maintain. Specialized training is also required when using manual or automatic polishing machines.

Optical connector information can be found on page 6-9.

Optical Fiber Splicing

There may be cases, such as repair or rearrangement, when optical fiber cables may need to be spliced. Splicing can be achieved by either fusion (welding) or mechanical process. Both processes have their applications and benefits. Each requires special equipment and differing levels of skill. The subject of splicing is a rather lengthy and complex one and as a result, will not be discussed further here. However, if you require additional information, contact your local optical fiber distributor.

Optical Fiber System Components

Optical Fiber Systems consist of active and passive components. Active components are devices such as optical transmitters, receiver and repeaters. Repeaters are used strictly in long-haul telecommunication applications. In premises optical fiber systems, transmitters and receivers are found in intelligent wiring hubs and on Network Interface Cards (NIC). For more information on these devices, contact your distributor.

Passive components include optical fiber cables, patch panels, patch cords, optical connectors and adapters. Compared to active components, passive components do not generate or re-generate optical signals, however they do introduce attenuation and signal loss to the signal as it passes through it. When selecting components for a premises optical fiber system, it is important to ensure that the combined loss of all components and splices is well within the Link Loss Budget of the optical equipment being used.

Patch Panels

Patch panels are the locations where fiber cables are to be terminated and the individual fibers connected to an administration panel via the use of adapter sleeves. Once connected to the connector panel, a patch cord is used on the front of the panel to connect the optical fiber to the electronic equipment, such as a wiring hub. Panel locations include wiring closets, main distribution rooms and where building entrance facilities are to be located. Patch panels provide strain relief and protection for fiber connectors and splices. They also provide convenient test and demarcation points as well as simplify fiber cable management.

Patch Panel product information can be found on page 6-23.
Adapter information can be found on page 6-34.

Patch Cords

There are a number of patch cords available, depending on the connector type and length required. Single, dual or quad fiber patch cords are also available.

The most common patch cord used today is the duplex (dual) fiber. The reason for this is that in order for optical fiber systems to function, a separate connection is required to transmit and receive optical signals. There are two types of dual fiber patch cords available: breakout and zip cord.

A single (simplex) patch cord is a single optical fiber within a single cable sheath. This type of cord is typically used as a pigtail in mechanical or fusion splicing applications.

A duplex zip patch cord is made of two fibers placed side by side and held together by a common membrane. This type of patch cord is smaller in size and more flexible than the breakout patch cord. Zip patch cords are commonly used in wiring closet and workstation applications.

Fiber patch cords information can be found on page 6-15.

Optical Fiber System Testing

Optical fiber testing is required to ensure that light entering one end of the fiber arrives at the other end in a usable manner. Continuity and optical power loss are the two most common tests performed today.

A continuity test verifies the integrity of the optical fiber link.

An optical power loss test determines the amount of optical signal attenuation throughout the entire link. This test verifies the integrity of all optical splices and connections in the fiber link.

A simple LED light or laser source and power meter or an Optical Time Domain Reflectometer (OTDR) can be used to perform tests. The OTDR can pinpoint sources of light loss and fiber breaks.

The OTDR sends a light pulse into the fiber, then measures the amount of signal reflected, much like radar. Connector pairs, splices, cable bends and termination points cause the light to be reflected. The greater the reflection, the greater the loss. The OTDR is able to pinpoint reflection locations through a complex series of calculations involving the speed of light, the strength of the light pulse, the strength of the reflected signal and the capabilities of the cable being tested.

Optical Fiber System Design

When planning an optical fiber system, a number of items need to be addressed prior to developing a list of required passive components, as they will have a direct impact on the components used.

- Special building considerations
- Network application(s) to be implemented
- Location of optical equipment
- System capacity requirements (growth)
- Standards compliance
- Length of each run
- Link loss budget.

In developing the passive components required for your optical system, review the checklist below to see if anything is missing.

- What type of fiber is to be used? (Multimode or Single-mode)
- What type of optical fiber cable construction will be used? (loose-tube or tight buffered)
- What type of fiber cable? (distribution, breakout, plenum or riser)
- Backbone only or fiber-to-the-desk application?
- Connector type. (ST Compatible, or SC)
- Location of patch panels? (wall or rack mounted in wiring closets or communication rooms)
- Interconnection or cross-connect?

Optical Fiber Standards

There are presently two major industry standards that provide optical fiber specifications to safely support present-day and future commercial applications.

The ANSI TIA/EIA-568-A (CSA 529-95) Commercial Building Wiring Standard provides recommendations in a number of areas including:

- Horizontal media specifications
- Backbone media specifications
- Adapters and connectors
- Splicing
- Fiber polarization (transmit and receive)

Optical fiber is now recognized as a horizontal medium for use in data applications. The recommendation calls for two 62.5/125 µm fibers to each workstation. This cable must be capable of supporting applications in excess of 1 GHz for the 90 m specified for horizontal cabling.

For backbone distribution, the Standard specifies the use of either 62.5/125 µm Multimode fiber or Single-mode fiber. The standard also provides information on how fibers should be bundled and identified. Maximum distances for each fiber mode type are also listed.

Adapter and connector specifications as well as splicing information can also be found in this Standard.

For a copy of this Commercial Building Wiring Standard, contact Global Engineering Documents.

ANSI X3T9.5 PMD Document provides connector, cable and distance specifications to safely support 100 mbps FDDI data application. Contact the American National Standards Institute for more information about this document.