Light It Up:

Optical Fiber Transmission, Media, and Applications

It may be surprising to learn that the idea of using light waves to transmit voice signals is well over a century old. In fact, Alexander Graham Bell's "photophone" invention used a narrow beam of sunlight focused on a thin mirror that vibrated when hit by human sound waves to transmit voice signals over distances up to 700 feet in 1880! The foundation for modern techniques of transmitting light energy was set in the 1960's when ruby lasers were first demonstrated and in the 1970's when workers at Corning Glass Works produced the first optical fiber with signal losses less than 20 dB/km. Since then, tremendous strides have been made in the refinement of semiconductor laser and light emitting diode light sources, as well as the optical fiber cables and components used to support the transmission of light energy.

While optical fiber cabling expertise is commonly thought to fall within the domain of service providers, it can not be overlooked that optical fiber cabling plays an important role in supporting customer-owned telecommunications infrastructures as well. Beyond supporting long-length runs installed between buildings or points in a customer-owned campus environment (commonly referred to as "outside plant cabling"), it's interesting to note that, on average, 20% of the cabling installed in the enterprise and 40% of the cabling installed in the data center (particularly between storage devices) is optical fiber cabling. While balanced twisted-pair copper cabling may still be the media of choice due to familiarity, perceived ease-of-termination compared to optical connections, and significantly lower equipment costs, the following benefits are compelling reasons to consider optical fiber cabling in your IT infrastructure:

- Extended distance support beyond the balanced twisted-pair limit of 100 meters
- Smaller media (e.g. two category 6A cables occupy the same space as one 216 fiber cable)
- Lighter media (e.g. 108 category 6A cables weighing 1,000 pounds or one 216-fiber cable weighing 40 pounds can be used to support 108 channels that are 200 feet long)
- Significantly higher port density in the telecommunications closet and line card density in the data center (up to 1,728 in a 4U housing)
- Smaller pathways required for fiber
- Improved air flow due to less cable damming
- Media robustness; optical fiber cabling can withstand double the pull tension of balanced twisted-pair cabling (50 lbf versus 25 lbf)
- Reduced equipment power consumption and cooling costs
- Centralized optical cabling may be used when deploying centralized equipment in the horizontal to eliminate the need for an optical cross-connect
- Support of passive optical LAN (POL) solutions
- Immune to electromagnetic and radio frequency interference (EMI/RFI)
- Immune to lightning strikes

Signal Transmission over Optical Fiber Cabling:
Optical communication is the transmission of photon (or light) energy through a low-loss waveguide whose function is to propagate the light signals over long distances. In telecommunications systems, the source of the photon energy may be a light emitting or a semiconductor laser diode, whose function is to produce light energy at a single wavelength. By turning the light source on and off quickly, streams of ones and zeros can be transmitted to form a digital communications channel. LED and laser light sources vary considerably with respect to their cost, transmit speed, and physical properties. Refer to *table 1* for an overview of the three light sources used in optical fiber telecommunications systems.

Table 1: Summary of Optical Light Sources

Light Source Type	Cost	Speed	Transmission Wavelength	Source Aperture (approx)
LED: (Light Emitting Diode)	Low	≤100 Mb/s	850 nm	100 µm
VCSEL: "Vertical Cavity Surface Emitting Laser" (Semiconductor laser diode)	Mid	≥ 1 Gb/s	850 nm 1300 nm	35 µm
Laser: (Fabrey-Perot edge-emitting semiconductor laser diode)	High	≥ 1 Gb/s	1310 nm 1550 nm	10 µm

The wavelength of the optical light source describes the frequency of the transmitted light wave (the longer the wavelength, the lower the frequency of the light wave) and has been selected to best match the transmission properties of recognized optical fiber types. A helpful analogy is to think of "wavelength" as the color of the light signal that is being transmitted. As shown in *figure 1*, the common optical communications wavelengths of 850 nm to 1550 nm fall between the ultraviolet and microwave frequencies in the light spectrum.

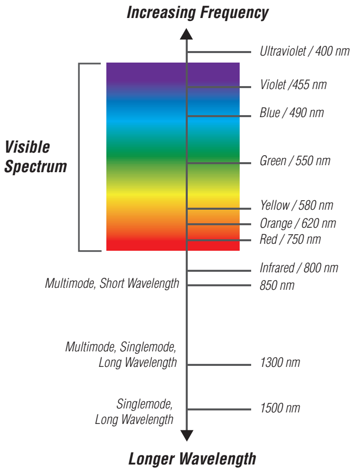
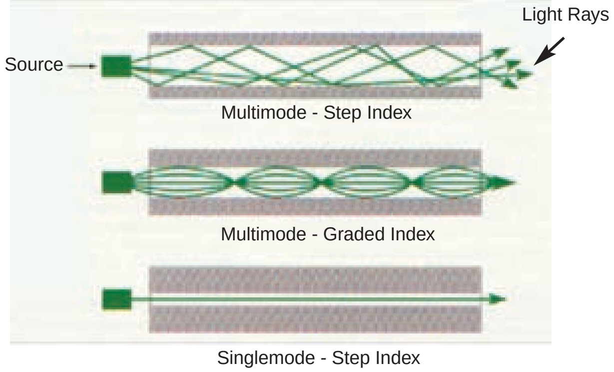


Figure 1: Light Spectrum

Source aperture describes the width of the transmitted light signal pulse. This characteristic is also related to the diameter of the optical fiber (the "waveguide") that will optimally transmit the light pulses; which helps to explain why there are several types of optical fiber cabling systems available. Larger diameter optical fiber (e.g. 62.5µm and 50µm) is required to adequately support transmission of light sources with larger apertures such as LED's and VCSEL's by minimizing signal loss and maximizing transmit distances. Small diameter optical fiber (e.g. 9µm) is required to adequately support transmission of laser light sources.

As a result of the variance in source aperture and optical fiber size, there are two ways that light can propagate through optical fiber. Since 62.5µm and 50µm optical fiber diameters are relatively large compared to the wavelength of the transmitted light signal (i.e. 850 nm to 1550 nm), there are many paths or "modes" that light energy may take when it propagates through the optical fiber. This type of transmission is referred to as multimode. Since the 9µm optical fiber diameter is similar to the wavelength of the transmitted light signal, only the one wavelength associated with transmission propagates through the optical fiber. This type of transmission is referred to as singlemode.

Figure 2: Multimode and Singlemode Light Propagation



Careful examination of multimode signal propagation quickly raises a concern about how the design of the optical fiber itself may adversely impact signal propagation. The earliest optical fiber design, referred to as step index, was constructed with a uniform index of refraction. This meant that all energized paths of light, whether propagating at the core or at the edge of the optical fiber, traveled at the same speed. The undesired result is that, over some distance, the energized modes in a step index optical fiber will support different path lengths and the output pulse will subsequently have a lower amplitude and wider spread (longer duration) than the input pulse due to the faster and slower light paths. Modal dispersion describes the degree to which the output pulse has spread compared to the input pulse and effectively limits the bit rate or bandwidth of the step index optical fiber to 20 - 30 million signal cycles per second transmitted over the distance of one kilometer (20-30 MHz · km). To compensate for this phenomenon, graded index optical fiber is constructed so that the index of refraction gradually changes from a maximum at the center ("slowing" the light signal) to a minimum ("speeding up" the light signal) near the edge of the optical fiber. This increases the bandwidth of graded-index fiber to greater than 1 billion signal cycles per second transmitted over the distance of one kilometer (1 GHz · km). Virtually all multimode fibers manufactured today are graded index. Since singlemode optical fiber supports only one wavelength of light, modal dispersion is not a concern for this media.
See *figure 2* for examples of multimode and singlemode light propagation.

An additional improvement to multimode optical fiber design involves optimizing the media to specifically support the VCSEL light source. Because the source aperture of an LED light source exceeds the diameter of the largest optical fiber suitable for telecommunications (62.5µm), all modes of a multimode fiber are energized and the pulse output is fairly easy to control with graded index optical fiber. However, since the source aperture of a VCSEL light source is much less than the diameter of the smallest optical fiber suitable for telecommunications (50µm), only a portion of the available transmission paths in a multimode fiber are energized. Second generation "laser-optimized" graded-index optical fiber is even more tightly specified to ensure that the pulse output of a VCSEL source exhibits well-controlled and limited modal dispersion.

In consideration of next generation applications that will employ more complex transmission schemes, such as transmitting more than one wavelength over a single fiber (e.g. wavelength division multiplexing), emphasis is placed on ensuring that optical fibers have a smooth attenuation profile over the range of possible transmission wavelengths. Of particular concern is attenuation increase in the 1360 – 1480 nm (the "E Band" or "water peak") range due to hydroxyl (also specified as OH^-) ions that are absorbed into singlemode fibers during the manufacturing process. Low water peak (LWP) singlemode fibers have undergone an additional manufacturing step to reverse the water absorption and have a nearly smooth attenuation profile. Zero water peak (ZWP) singlemode fibers undergo a more complex process which eliminates all losses in the water peak range and further lowers attenuation loss across the entire spectrum.

The many variables associated with optical fiber transmission, including the capabilities of the light source, modal dispersion, chromatic dispersion (a second order effect characterizing slight shifts in the transmit light spectrum), bandwidth, and losses in the transmission line contribute to the bit rate and distance capabilities of various optical fiber media. In general, lasers transmitting over singlemode fiber support the highest bandwidth and longest distance while LED's transmitting over large diameter (62.5µm) multimode fiber support the lowest bandwidth and shortest distances.

Media Selection:
Unlike balanced twisted-pair media, optical fiber cabling can be considered an application dependent media. This means that considerations such as distance, application, and equipment cost plays a significant role in the media selection process.

TIA and ISO (through reference to IEC and ITU-T specifications) recognize six grades of multimode and singlemode optical fiber as shown in *table 2.* Physical dimensions related to the optical fiber (e.g. diameter, non-circularity, and mechanical requirements) and optical specifications (e.g. attenuation and bandwidth) are specified. It is important to keep in mind that these specifications are for the "raw" optical fiber before it is subjected to the cabling process. TIA and ISO use these optical fiber requirements to then specify requirements for OM1, OM2, OM3, OM4, OS1, and OS2 optical fiber cables and cabling.

Table 2: Optical Fiber Types and Standards References

Optical Fiber Type	Description	TIA and ISO Standard Reference
OM1	62.5µm Multimode	TIA 492AAAA-B IEC 60793-2-10 A1a.1 type
OM2	50µm Multimode	TIA 492AAAB-A IEC 60793-2-10 A1a.2 type
OM3	850nm laser-optimized 50µm Multimode	TIA 492AAAC-B IEC 60793-2-10 Ed 4.0 A1b type
OM4	850nm laser-optimized high bandwidth 50µm Multimode	TIA 492AAAD IEC 60793-2-10 Ed 4.0 A1a.3
OS1	Singlemode	TIA 492CAAA IEC 60793-2-50 Ed 4.0 B1.1 type (see also ITU-T G.652 a/b)
OS2	Singlemode for outdoor loose-tube constructions	TIA 492CAAB IEC 60793-2-50 Ed 4.0 B1.3 type (see also ITU-T G.652 c/d)

While media selection may seem onerous, comparing the throughput and distance needs in your target environment against a performance chart such as shown in *table 3* is a good way to initiate the selection process. Although this and other similar tables may lead to the conclusion that singlemode fiber is the optimum media under all scenarios, there are trade-offs to consider related to the cost of optoelectronics and application implementation. In particular,

- Singlemode optoelectronics rely on much more powerful and precise light sources and can cost 2 - 4 times more than multimode optoelectronics
- Multimode media is typically easier to terminate and install in the field
- It is always more cost effective to transmit at 850nm for multimode applications and at 1310 nm for singlemode applications
- Optoelectronics that use multiple transmit lasers (e.g. 10GBASE-LX4 uses four separate laser sources per fiber) or other multiplexing techniques cost significantly more than optoelectronics that transmit over one wavelength

A good rule of thumb is to consider multimode fiber to be the most cost-effective choice for applications up to 550 meters in length.

Table 3: Supportable Application Distances by Fiber Type (meters)

Application	**OM1**		**OM2**		**OM3**		**OM4**		**OS1/OS2**	
Wavelength (nm)	850	1300	850	1300	850	1300	850	1300	1310	1550
FDDI PMD	-	2,000	-	2,000m	-	2,000m	-	2,000m[5]	-	-
FDDI SMF-PMD	-	-	-	-	-	-	-	-	10,000m	-
10/100BASE-SX	300m	-	300m	-	300m	-	300m[5]	-	-	-
100BASE-FX	-	2,000m	-	2,000m	-	2000m	-	2,000m[5]	-	-
1000BASE-SX	275m	-	550m	-	800m	-	800m[5]	-	-	-
1000BASE-LX	-	550m	-	550m	-	800m	-	800m[5]	5,000m	-
10GBASE-S	33m	-	82m	-	300m	-	550m[5]	-	-	-
10GBASE-LX4[1]	-	300m	-	300m	-	300m	-	300m[5]	10,000m	-
10GBASE-L	-	-	-	-	-	-	-	-	10,000m	-
10GBASE-LRM	-	220m	-	220m	-	220m	-	220m[5]	-	-
10GBASE-E	-	-	-	-	-	-	-	-	-	40,000m
40GBASE-SR4[2]	-	-	-	-	100m	-	150m	-	-	-
40GBASE-LR4[1]	-	-	-	-	-	-	-	-	10,000m	-
40GBASE-ER4[4]	-	-	-	-	-	-	-	-	-	40,000m
100GBASE-SR10[3]	-	-	-	-	100m	-	150m	-	-	-
100GBASE-SR4[2,4]	-	-	-	-	70m[4]	-	100m[4]	-	-	-
100GBASE-LR4[1]	-	-	-	-	-	-	-	-	10,000m	-
100GBASE-ER4[1]	-	-	-	-	-	-	-	-	-	30,000m

[1] 4 transmit wavelengths per fiber (8 optical transmitters and 8 optical receivers required per link or channel)
[2] 4 transmit and 4 receive fibers required (8 fibers per link or channel)
[3] 10 transmist and 10 receive fibers required (20 fibers per link or channel)
[4] Under development by the IEEE 802.3bm 40 Gb/s and 100 Gb/s Fiber Optic Task Force
[5] OM4 distance support of legacy applications has not been established by Standards committees

Optical Fiber Cabling Configurations:
Optical fiber cabling is typically deployed in pairs (one fiber is used to transmit and one fiber is used to receive). Due to its extended distance support of applications compared to balanced twisted-pair cabling, optical fiber cabling is the perfect media for use in customer-owned outside plant (OSP), backbone cabling, and centralized cabling applications.

Customer-owned OSP cabling is deployed between buildings in a campus environment and includes the terminating connecting hardware at or within the structures. Interestingly, customer owned OSP cabling is typically intended to have a useful life in excess of thirty (30) years, so great care should be taken to specify robust cabling media. Requirements pertaining to customer-owned outside plant cabling and pathways can be found in ANSI/TIA-758-A[1] and BS EN 50174-3[2] .

Backbone cabling is deployed between entrance facilities, access provider spaces, service provider spaces, common equipment rooms, common telecommunications rooms, equipment rooms, telecommunications rooms, and telecommunications enclosures within a commercial building. Backbone cabling must be configured in a star topology and may contain one (main) or two (main and intermediate) levels of cross connects. Backbone cabling requirements are specified in ANSI/TIA-568-C.0[3] , ANSI/TIA-568-C.1[4] , and ISO/IEC 11801 2nd, Edition[5] .

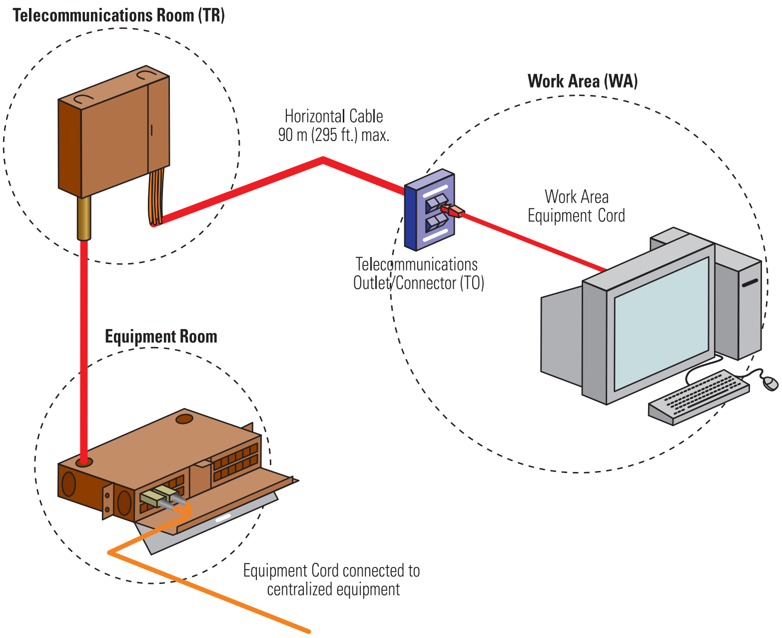


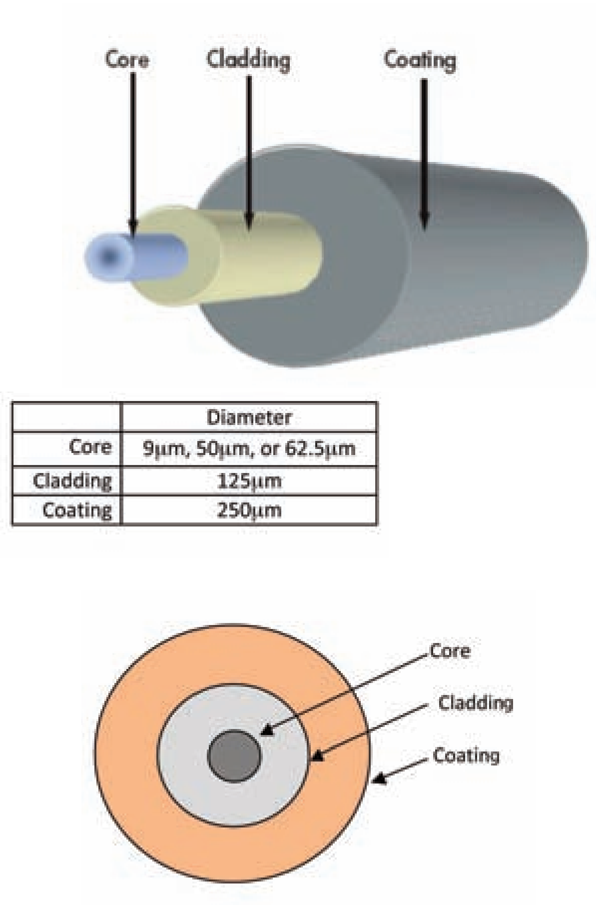
Figure 3: Centralized Optical Fiber Cabling using an Interconnection

Centralized optical fiber cabling may be deployed as an alternative to the optical cross-connect to support centralized electronics deployment in single tenant buildings. Centralized optical fiber cabling supports direct connections from the work area to the centralized cross-connect via a pull-through cable and the use of an interconnect or splice in the telecommunications room or enclosure. Note that the maximum allowed distance of the pull-through cable between the work area and the centralized cross-connect is 90 m (295 ft). Centralized cabling requirements are specified in ANSI/TIA-568-C.0 and ISO/IEC 11801 2nd Edition. A typical schematic for centralized optical fiber cabling using an interconnection is show in *figure 3*.

Optical fiber cabling may also be used in the horizontal cabling infrastructure, although there are no provisions allowing extended distances in the TIA and ISO Standards.

Horizontal cabling is deployed between the work area and the telecommunications room or enclosure. Horizontal cabling includes the connector and cords at the work area and the optical fiber patch panel. A full cross-connect or interconnect may be deployed along with an optional multi-user telecommunications outlet assembly (MUTOAs) or consolidation point (CP) for a total of four connectors in the channel. The maximum horizontal cable length shall be 90 m (295 ft) and the total length of work area cords, patch cords or jumpers, and equipment cords shall be 10 m (32 ft) for both optical fiber and balanced twisted-pair cabling channels. Horizontal cabling requirements are specified in ANSI/TIA-568-C.0, ANSI/TIA-568-C.1, and ISO/IEC 11801, 2nd Edition.

Optical Fiber Cable:
The optical fiber that enables light transmission is actually an assembly of 3 subcomponents: the core, the cladding, and the coating. The core is made of glass (or, more accurately, silica) and is the medium through which the light propagates. The core may have an overall diameter of 9 µm for singlemode or 50µm or 62.5µm for multimode transmission. Surrounding the glass is a second layer of glass with a vastly different index of refraction that focuses and contains the light by reflecting it back into the core. This second layer is called the cladding and, regardless of the glass core construction, has an overall diameter of 125µm. Combining the core and cladding diameters is the source of optical fiber descriptors, such as 50/125µm or 62.5/125µm, that are applied to optical fibers commonly used for telecommunications applications. The purpose of the outermost layer, called the coating, is to add strength and build up the outer diameter to a manageable 250µm diameter (about 3 times the diameter of a human hair). The coating is not glass, but rather a protective polymer, such as urethane acrylate, that may be optionally colored for identification purposes. See *figure 4* for a cross-sectional view of an optical fiber.



	Diameter
Core	9µm, 50µm, or 62.5µm
Cladding	125µm
Coating	250µm

Figure 4: Optical Fiber Cross-Section

Cabling optical fibers makes them easier to handle, facilitates connector termination, provides protection, and increases strength and durability. The cable manufacturing process differs depending upon whether the optical fibers are intended for use in indoor, outdoor, or indoor/outdoor environments.

Indoor optical fiber cables are suitable for inside (including riser and plenum) building applications. To facilitate connector terminations, a 900µm plastic buffer is applied over the optical fiber core, cladding, and coating subassembly to create a tight buffered fiber. Up to 12 tight buffered fibers are then encircled with aramid yarns for strength and then enclosed by an overall flame-retardant thermoplastic jacket to form a finished optical fiber cable. For indoor cables with higher than 12-fiber counts, groups of jacketed optical fiber cables (typically 6- or 12-fiber count) are bundled together with a central strength member (for support and to maintain cable geometry) and are enclosed by an overall flame-retardant thermoplastic jacket. Supported fiber counts are typically between 2 and 144.

Outdoor (also known as outside plant or OSP) optical fiber cables are used outside of the building and are suitable for lashed aerial, duct, and underground conduit applications. To protect the optical fiber core from water and freezing, up to 12 250µm optical fiber cores are enclosed in a loose buffer tube that is filled with water-blocking gel. For up to 12-fiber applications, the gel-filled loose tube is encircled with water-blocking tapes and aramid yarns and enclosed within an overall ultraviolet and water resistant black polyolefin jacket. For outdoor cables with higher than 12-fiber counts, groups of loose buffer tubes (typically 6- or 12-fiber count) are bundled together with a central strength member and water-blocking tapes and aramid yarns and then enclosed within an overall ultraviolent and water resistant black polyolefin jacket. Corrugated aluminum, interlocking steel armor, or dual jackets may be applied for additional protection against crushing and rodent-damage. Supported fiber counts are typically between 12 and 144.

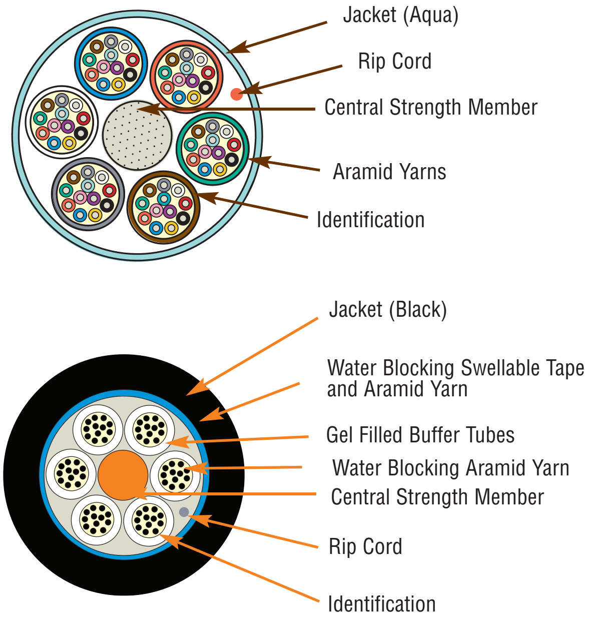


Figure 5: Sample Optical Fiber Cable Constructions

Indoor/outdoor optical fiber cables offer the ultraviolet and water resistance benefits of outdoor optical fiber cables combined with a fire retardant jacket that allows the cable to be deployed inside the building entrance facility beyond the maximum 15.2 m (50 ft) distance that is specified for OSP cables. (Note that there is no length limitation in countries outside of the United States that do not specify riser or plenum rated cabling.) The advantage of using indoor/outdoor optical fiber cables in this scenario is that the number of transition splices and hardware connections is reduced. Indoor/outdoor optical fiber cables are similar in construction to outdoor optical fiber cables except that the 250µm optical fiber cores may be either tight buffered or enclosed within loose buffer tubes. Loose tube indoor/outdoor optical fiber cables have a smaller overall diameter than tight buffered indoor/outdoor optical fiber cables, however tight buffered indoor/outdoor cables are typically more convenient to terminate because they do not contain water-blocking gel or require the use of breakout kits.

Table 4: Optical Fiber Cable Transmission Performance

Optical Fiber Type	Wavelength (nm)	Maximum Attenuation (db/km)	Minimum Overfilled Modal Bandwidth (MHz•km)	Minimum Effective Modal Bandwidth (MHz•km)
OM1	850 1300	3.5 1.5	200 500	n/s
OM2	850 1300	3.5 1.5	500 500	n/s
OM3	850 1300	3.5 1.5	1500 500	2000 n/s
OM4	850 1300	3.5 1.5	3500 500	4700 n/s
Inside Plant (OS1 and OS2[1])	1310 1550	1.0 1.0	n/a	n/a
Indoor-Outdoor (OS1 and OS2[1])	1310 1550	0.5 0.5	n/a	n/a
Outside Plant (OS1 and OS2[1])	1310 1550	0.5 0.5	n/a	n/a

[1] OS2 is commonly referred to as "low water peak" singlemode fiber and is characterized by having a low attenuation coefficient in the vicinity of 1383 nm

Figure 5 shows examples of 72-fiber optical cables featuring tight buffered indoor and loose tube outdoor constructions. Optical fiber cable is characterized by its maximum attenuation, minimum overfilled modal bandwidth (LED light source - multimode only), and minimum effective modal bandwidth (VCSEL light source – multimode only) per kilometer at two transmission wavelengths as shown in *table 4*.

Optical Fiber Interconnections:

Unlike the plug and jack combination that comprises a mated balanced twisted-pair connection, an interconnection is used to mate two tight-buffered optical fibers. An optical fiber interconnection typically consists of two plugs (connectors) that are aligned in a nose-to-nose orientation and held in place with an adapter (also called a coupler or bulkhead). The performance of the optical fiber interconnection is highly reliant upon the connector's internal ferrule and the adapter's alignment sleeve. These components work in tandem to retain and properly align the optical fibers in the plug-adapter-plug configuration. The internal connector ferrule is fabricated using a high-precision manufacturing process to ensure that the optical fiber is properly seated and its position is tightly controlled. The high-tolerances of the alignment sleeve ensure that the optical fibers held in place by the ferrule are aligned as perfectly as possible. Although more expensive, ceramic alignment sleeves maintain slightly tighter tolerances than metal or plastic alignment sleeves, are not as susceptible to performance variations due to temperature fluctuations, and may be specified for extremely low loss applications. All Siemon adapters come standard with ceramic alignment sleeves. See *figure 6* for an example of an optical fiber plug-adapter-plug configuration.

Figure 6:
Optical Fiber Plug-Adapter-Plug Configuration

Accurate plug-adapter-plug alignment minimizes light energy lost at the optical fiber interconnection and maintaining precision tolerances becomes especially critical as the optical fiber diameter decreases. For example, if two 62.5µm optical fibers are off-center by 4 µm in opposite directions, then 13% of the light energy escapes or is lost at the interconnection point. This same misalignment in a 9µm singlemode fiber would result in almost a total loss of light energy! The critical nature of the core alignment is the reason why different optical fiber types, including 62.5µm and 50µm multimode fiber, should never be mixed in the same link or channel.

Optical fiber breakout kits are used to facilitate termination of loose-tube optical fibers used in indoor/outdoor and outdoor applications. Once the water-blocking gel is thoroughly removed from the optical fibers, the breakout kit allows furcation tubes (typically 1.2mm to 3.0mm in diameter) to be installed over the 250µm optical fibers; increasing the diameter and forming a short "jacket" so that the optical fibers may be terminated to the desired optical fiber connector. Selection of the correct furcation tube ensures compatibility with all optical fiber connectors.

There are many choices for the optical fiber connector. Traditional optical fiber connectors are represented by the SC and ST connector styles. These two types of optical fiber connectors were recognized when optical fiber cabling was described in the first published TIA and ISO/IEC telecommunications cabling Standards. The ST connector features a round metal coupling ring that twists and latches onto the adapter and is only available as a simplex assembly (two assemblies are required per link or channel). SC connectors feature a quick push-pull latching mechanism and have an advantage in that they may be used in conjunction with a duplexing clip that more easily supports the interconnection of the 2 optical fibers in a link or channel. SC optical fiber connectors are generally recommended over ST optical fiber connectors for use in new installations due to their duplexing capability. Both ST and SC connectors may be field-terminated using an epoxy polish or mechanical splice method. In addition, the SC connector may be quickly and reliably field-terminated using Siemon's proven XLR8® mechanical splice technology.

Small form factor (SFF) refers to a family of optical fiber interfaces that support double the connector density of traditional optical fiber connectors. The most common SFF interface is the LC connector; with the MT-RJ having some limited legacy market presence. Both interfaces feature duplex configurations and a small pluggable form with external plug latch that is approximately the same size as the 8-position modular plug used for copper connections. The LC connector may by field-terminated using an epoxy polish method or mechanical splice method such as Siemon's XLR8 technology. The MT-RJ connector is field-terminated using a traditional no-epoxy/no-polish mechanical splice termination method. The main difference between the MT-RJ and LC optical connector is related to the performance of the internal ferrule. The internal ferrule of the LC connector maintains sufficiently tight tolerances to fully support both singlemode and multimode applications, while the MT-RJ connector is recommended for use in legacy applications only. Siemon does not recommend field termination of MT-RJ connectors for singlemode applications.

Array optical fiber connectors are the latest recognized style of optical fiber interfaces and are intended to support extremely high density environments (e.g. those supporting 40GBASE-SR4 and 100GBASE SR10), as well as emerging technologies such as 100GBASE-SR4 and 100GBASE LR4 that will require more than 2 optical fibers per link or channel. There are typically 12 or 24 fibers in an array connector, although one array connector may support as many as 144 fibers. A multi-fiber push on (MPO) style interface is the most basic array interface. MTP® optical fiber connectors are intermateable with MPO connectors including those used in active equipment; however they are engineered to deliver improved mechanical and optical performance and are recommended for deployment in new installations. MPO/MTP connectors cannot be field terminated. Array or "plug & play" modules are self-contained and typically support the interconnection of two 12-fiber MPO/MTP interfaces with 24 LC connections or one 12-fiber MPO/MTP interface with 12 SC or LC connections.

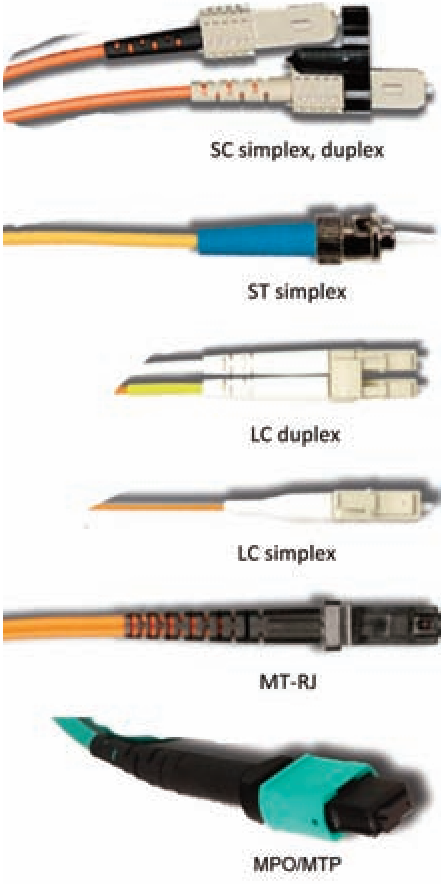


Figure 7: Common Optical Fiber Connectors

Optical fiber connector performance is specified for the parameters of insertion loss (0.75 dB maximum) and return loss (20 dB minimum for multimode, 26 dB minimum for singlemode, and 55 dB minimum for singlemode used to support broadband analog video (e.g. CATV) applications). Examples of common optical fiber connectors are shown in *figure 7.*

Optical Fiber Cabling Deployment:
The most common optical fiber cabling deployment approach is to field terminate the optical fiber connectors to the optical fiber cable using the appropriate epoxy polish or no-epoxy/no polish mechanical termination method. However, the MPO/MTP plug and play modules and MPO/MTP array connectors are not supported by field termination and there are other considerations, such as installer expertise and the IT construction/upgrade schedule, which may favor the use of factory-terminated pigtails or trunking assemblies over field termination methods. The pros and cons of each of these methods are described below.

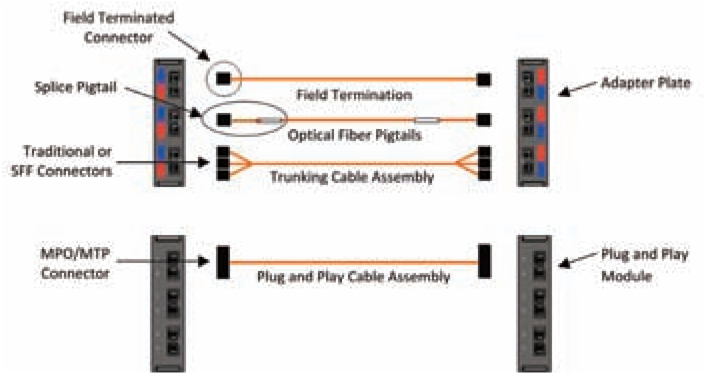


Figure 8: Optical Fiber Cable Deployment Options

Field termination supports the lowest raw material cost for SC, ST, LC, and MT-RJ optical fiber cabling systems. However, the time needed for field-termination is the longest of the three deployment options and installer skill level requirements are higher, which may increase the project installation cost. No-epoxy/no-polish termination methods require less installation skill than the epoxy polish method, however the connectors used in conjunction with mechanical termination methods are more expensive and the performance (especially using the no-epoxy/no polish method) may be lower and more variable.

Optical fiber pigtails feature a factory pre-terminated and tested SC, ST, LC or MT-RJ optical fiber connector and a 1 meter stub of 62.5/125µm multimode, 50/125µm multimode, or singlemode optical fiber. The stub end of the pigtail is then fusion spliced to the optical fiber. Fusion splicing provides a consistent, nearly loss-free termination and can be fast with proper technicians and equipment. The main benefits to this approach are the assurance of low-loss performance at the interconnection and the elimination of the need for end-face inspections and possible connector re terminations.

Figure 9: Optical Fiber Deployment Options Comparison

	Materials Cost	Installation Speed	Skill Level	Multimode 40/100GbE Ready
Field Termination	$	Slow[1]	Med[1] - High	No
Optical Fiber Pigtails	$	Slow	High	No
Trunking Cable Assemblies	$	Medium	Medium	No
Plug and Play Cable Assemblies	$$$	Fast	Low	Yes[2]

[1] Siemon's proven XLR8 mechanical splice technology is significantly faster and less complex than traditional no epoxy/no polish mechanical termination methods.
[2] 8 multimode fibers are required to support 40GBASE-SR4 and 20 multimode fibers will be required to support 100GBASE-SR10.

Trunking cable assemblies provide an efficient alternative to field-terminated components or splice connections and allow up to 75% faster field deployment times. Trunking cable assemblies are custom factory pre-terminated and tested lengths of optical fiber cable terminated on both ends with SC, ST, LC, MT RJ, or MPO/MTP optical fiber connectors that are simply pulled and plugged in. When deploying trunking cable assemblies, cable length specification is critical and precise planning is required up front. Trunking cable assemblies that have an MPO/MTP connector on one or both ends are commonly referred to as "plug and play" cable assemblies. MPO/MTP plug and play cable assemblies have the smallest connector profile and, therefore, have the smallest pathway, cabinet, and rack space requirements of all trunking cable assembly options.

Figure 8 shows examples of field-termination, optical fiber pigtail, trunking cable assembly, and MPO/MTP plug and play cable assembly deployment configurations. Figure 9 provides a representative comparison of the cost, speed, skill level, and future technology capability associated with each of the four deployment options.

Regardless of which optical fiber cable deployment option is selected, special care must be taken to maintain the polarity of the optical fibers to ensure that the transmit fiber is matched to the equipment receive port on each end of the optical fiber link or channel.

Optical fiber cabling is characterized by its link attenuation, which is calculated as the sum of cable attenuation and connector and splice insertion loss. Maximum allowable optical fiber link attenuation is application specific. Refer to the application tables in IEEE Std 802.3™-2012[6] , ANSI/TIA-568-C.0, and ISO/IEC 11801, 2nd Edition.

Resources:

Optical fiber cabling can significantly increase IT infrastructure flexibility by supporting extended distances, freeing up valuable pathway and rack space, operating over “greener” equipment, and providing a migration path to 40Gb/s and 100Gb/s Ethernet. Often, however, the multiple options that make optical fiber cabling such a flexible solution can make cabling infrastructure specification confusing. Fortunately, resources such as Siemon’s global Technical Services team and network of Certified Consultants and Installers are ready to assist you in specifying the highest performing cabling system to meet your demanding IT requirements.

Definitions:

Attenuation: See insertion loss
Chromatic dispersion: A measure of optical pulse scattering due to deviation from the source wavelength
Index of refraction: A characterization of how much the speed of light is reduced inside a given medium referenced to the speed of light in a vacuum
Insertion loss: Signal loss resulting from the insertion of a component, or link, or channel between a transmitter and receiver (often referred to as attenuation)
Modal dispersion: A measure of optical pulse deviation or spread resulting from differences in the propagation velocity of optical signals propagating along different paths
Multimode: An optical fiber designed to carry multiple optical signals, distinguished by different frequency or phase, at the same time
Multiplex: To combine multiple signals onto one channel
Photon: The fundamental energy unit associated with light
Singlemode: An optical fiber designed to carry only the single wavelength identified for transmission
Step index: An optical fiber that has a uniform index of refraction throughout its core
Wavelength division multiplexing: Simultaneously transmitting multiple light signals associated with more than one wavelength over a single optical fiber
Waveguide: A conduit used to pass photon or electron energy
Wavelength: A measure of the distance between repetitions of peaks in a light wave; it is measured in nanometers and can be thought of as the “color” of light transmitted

Acronyms:

dB/km: Decibels per kilometer; typically used to describe signal loss
EMI: Electromagnetic interference
Gb/s: Gigabits per second
GHz: One billion signal cycles per second
GHz · km: Gigahertz per kilometer; a non-scaleable measure of bandwidth
IEC: International Electrotechnical Commission
IEEE: Institute of Electrical and Electronics Engineers
ISO: International Organization for Standardization
IT: Information technology
LASER: Light Amplification by Stimulated Emission of Radiation
lbf: pound-force
LED: Light Emitting Diode
LWP: Low water peak
Mb/s: Megabit per second
MHz: One million signal cycles per second
MHz · km: Megahertz per kilometer; a non-scaleable measure of bandwidth
μm: micrometer or micron
MPO: Multi-fiber push on
nm: nanometer
OSP: Outside plant
RFI: Radio frequency interference
SFF: Small form factor
TIA: Telecommunications Industry Association
ITU-T: International Telecommunication Union – Telecommunication Standardization Sector
VCSEL: Vertical Cavity Surface Emitting Laser
ZWP: Zero water peak

References:

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