Multimode and Single-Mode Optical Fibers for LAN Systems

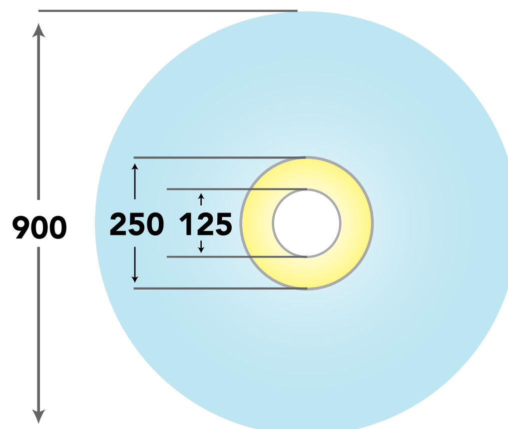
Two optical fiber categories with distinctive operational attributes are multimode and single-mode fibers. Within the multimode category, another important distinction is between step index and graded index. Further definition of fibers relates to physical size, optical performance, coatings, and strength.

All fibers consist of a number of substructures including:

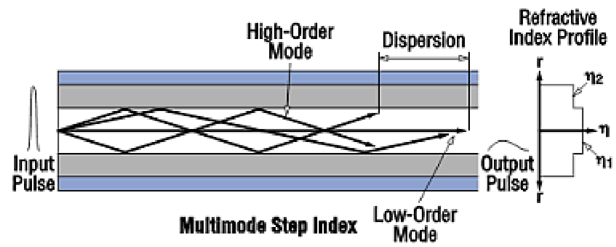
- a core, which carries most of the light, surrounded by
- a cladding, which bends the light and confines it to the core, surrounded by
- a substrate layer (in some fibers) of glass which does not carry light, but adds to the diameter and strength of the fiber, covered by
- a primary coating, which provides the first layer of mechanical protection, covered by a secondary buffer coating, which protects the relatively fragile primary coating and the underlying fiber.

Multimode Fiber

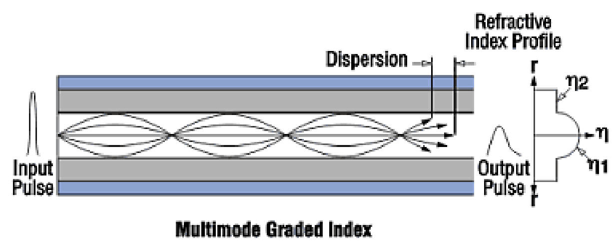
In the case of a multimode fiber, the core diameter is relatively large compared to a wavelength of light. Core diameters range from 50 micrometers (µm) to 1,000 µm, compared to the wavelength of light of about 1 µm. This means that light can propagate through the fiber in many different ray paths, or modes, hence the name multimode.



Two basic types of multimode fibers exist. The simpler and older type is a step index fiber, where the index of refraction (the ability of a material to bend light) is the same all across the core of the fiber. This leads to rays of light being propagated as shown right.



With all these different ray paths or modes of propagation, different rays travel different distances and take different amounts of time to transit the length of a fiber. This being the case, if a short pulse of light is injected into a fiber, the various rays emanating from that pulse will arrive at the other end of the fiber at different times. The output pulse will be of longer duration than the input pulse. This phenomenon is called "modal dispersion" (pulse spreading). It limits the number of pulses per second that can be transmitted down a fiber and still be recognizable as separate pulses at the other end. Therefore, this limits the bit rate or bandwidth of a multimode fiber. For step index fibers, wherein no effort is made to compensate for modal dispersion, the bandwidth is typically 20 to 30 MHz over a length of one kilometer of fiber expressed as "MHz-km."



In the case of a graded index multimode fiber, the index of refraction across the core is gradually changed from a maximum at the center to a minimum near the edges, hence the name graded index. This design takes advantage of the phenomenon that light travels faster in a low-index-of-refraction material than in a high-index material. The light rays or modes of propagation that travel near the edges of the core travel faster for a longer distance, thereby transiting the fiber in approximately the same time as the "low-order modes", or rays traveling more slowly near the center of the core.

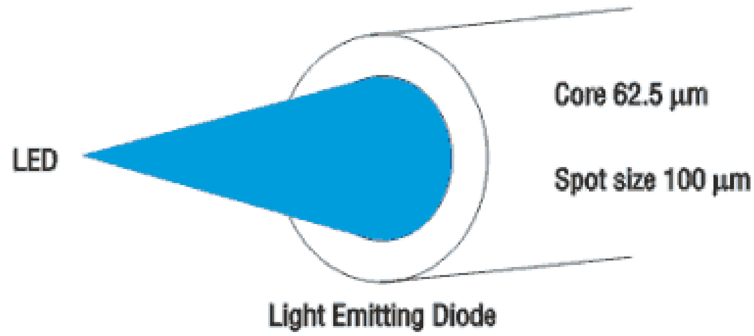
If a short pulse of light is launched into the graded index fiber, it may spread some during its transit of the fiber, but much less than in the case of a step index fiber. Therefore, multimode-graded index fibers have the ability to transport pulses closer together without spreading into each other than step index fibers. They can support a much higher bit rate or bandwidth. Typical bandwidths of graded index fibers range from 200 MHz-km to well over one GHz-km. The actual bandwidth depends on how well a particular fiber's index profile minimizes modal dispersion and on the wavelength of light launched into the fiber.

Multimode fibers are identified by the physical size of the core and the overall glass, often referred to as the cladding. The 62.5/125 fiber has historically been the most popular multimode fiber type used in North American LAN systems. The fiber numbers indicate a core diameter of 62.5 µm and a total glass diameter of 125 µm. Another common graded index multimode fiber in use today is the high bandwidth 50/125 used primarily in Europe and Asia LAN systems. The 100/140 fiber is an older LAN fiber, which is used in some industrial applications because of its large core size. It is decreasing in popularity due to its high cost and poor performance in attenuation and bandwidth.

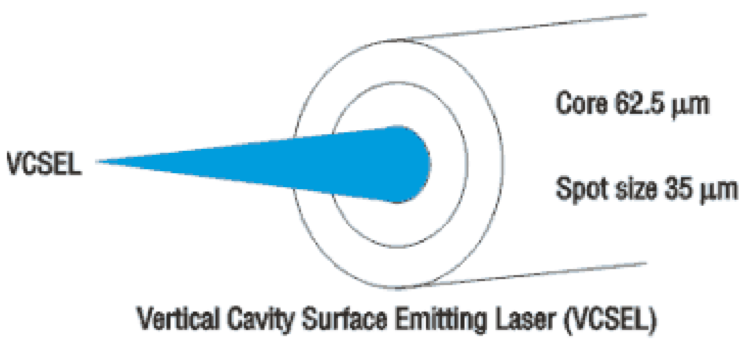
Some multimode fibers are made of a glass core and a plastic cladding. These are called "plastic-clad silica" or "PCS" fibers. They are inherently a step index profile, and exhibit a limited bandwidth of approximately 20 MHz-km to 30 MHz-km. The most successful implementation of this design is the "hard-clad silica" or "HCS" type fiber. The most common construction of this fiber is the 200/230 size used primarily in industrial control applications.

There is also a family of all-plastic fibers. These also have a step index profile with the expected low bandwidth. The plastic fibers are not as "clear" as the glass fibers and exhibit much higher attenuation, typically 200 dB/km, limiting their transmission distance to 50 to 100 meters. They typically have a very large core, a popular size being 1,000 µm in diameter. They are used in short-distance, limited-bandwidth applications such as industrial control systems.

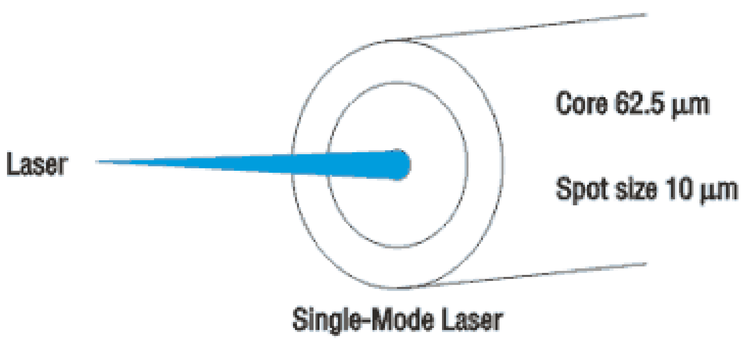
High Performance Multimode Fibers for Gigabit Ethernet Applications
Until Gigabit Ethernet systems became available, the fiber most widely used in LAN and private network applications was the FDDI grade 62.5 µm core fiber with 160 MHz-km bandwidth at 850 nm wavelength and 500 MHz-km at 1310 nm. The bandwidth of these fibers has been measured with an overfilled-launch light source, which illuminates the entire core of the fiber, to simulate the performance of the fiber when used with the broad illumination pattern of light-emitting diode (LED) light sources. More recently, many networks are being designed for use with Gigabit Ethernet systems utilizing laser light sources, which have a much smaller spot of light illuminating the fiber core at smaller incidence angles than LED light sources.



(A) FDDI Overfilled-Launch



(B) Gigabit Ethernet Short Wavelength



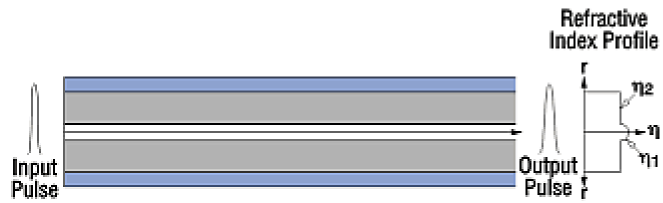
(C) Gigabit Ethernet Long Wavelength

This Vertical Cavity Surface Emitting Laser (VCSEL), (Shown in Figure 1 left), does not energize as many dispersive modes of the fiber waveguide as does the overfilled-launch of an LED, so the fiber modal dispersion and bandwidth performance are different than might be expected from the overfilled-launch measurements. Laser based Gigabit and 10-Gigabit Ethernet systems are instead distance-limited by the system effective modal bandwidth and the total link attenuation. In addition, Differential Mode Delay (DMD) is an important measure for all fibers used for 10-Gigabit Ethernet. The Laser Ultra-Fox™ laser optimized cables listed on the above chart have effective modal bandwidth and DMD specifically designed for use with Gigabit and 10-Gigabit Ethernet systems, while maintaining backward compatibility with existing LED based systems.

While DMD and the resulting effective modal bandwidth are important when determining the maximum distance rating of the cable, link attenuation is also a very important and often overlooked distance limitation factor. Both Gigabit and 10-Gigabit Ethernet systems have allowable link loss of half to one-third that of older 10 and 100 Megabit Ethernet systems. These extremely tight link budgets mean that every 0.1 dB cable loss can shorten the maximum achievable link distance. Optical Cable Corporation's Laser Ultra-Fox™ extended distance Gigabit and 10-Gigabit cables have 3.0 dB/km maximum attenuations at 850 nm instead of the 3.5 dB/km attenuation of many other cable manufacturers. This extra link margin can make the difference between a working extended distance link and a system failure.

Single-Mode Fiber

In the case of a single-mode fiber, the core diameter of about 9 µm is much closer in size to the wavelength of light being propagated, about 1.3 µm. This limits the light transmission to a single ray or mode of light to propagate down the core of the fiber.



Single-Mode Step Index

In single-mode fibers, all the multiple-mode or multimode effects described above are eliminated; however, one pulse-spreading mechanism remains. Just as in the multimode fibers, different wavelengths of light travel at different speeds causing short pulses of light injected into the fiber to spread as they travel. This phenomenon is called "chromatic dispersion". The amount of pulse spreading depends on the spectral width or number of wavelengths or colors the light source produces. The lasers typically used as light sources for single-mode systems produce a relatively pure light output, with a narrow spectral width, reducing the chromatic dispersion effect in single-mode fibers. Nonetheless, the pulse broadening produced by chromatic dispersion ultimately limits the bandwidth of single-mode systems.

Since fiber bandwidth determines the transmission distance capability of high-data-rate systems, several single-mode fiber designs have been developed to optimize this characteristic.

Single-Mode Fiber for Short-to-Moderate Distance Applications

When moderate distance transmission cannot be accomplished with multimode fiber and inexpensive multimode light sources, single-mode fiber is most commonly used in private network, campus, and building applications. It is designed for use at both 1310 nm and at 1550 nm wavelength windows. Because the 1310 nm lasers and detectors are less expensive than 1550 nm devices, most of these short-to-moderate distance applications use the 1310 nm wavelength. Single-mode fiber is the least expensive fiber available and is optimized for the lowest dispersion at 1310 nm. Single-mode fiber offers the best combination of cost and performance for most short-to-moderate distance private network, campus, and building applications when distances exceed multimode limits. Low water peak (enhanced) single-mode fiber is also available for such applications as Coarse Wavelength Division Multiplexing (CWDM).

Single-Mode Fiber for Long Distance Applications

Fibers for long distance applications are optimized at the 1550 nm wavelength window where the loss of the single-mode fiber is lowest; they are generally not used at the 1310 nm window. These long distance fibers are usually not used for short-to-moderate distance applications because of the high cost of the 1550 nm laser sources. Several types of single-mode fibers have been developed for long distance applications:

- **Dispersion Shifted Fiber**
  Dispersion shifted fiber was developed with a zero-dispersion wavelength at 1550 nm. This fiber works fine if only one laser is used, but it has dispersion non-linearities making it unsuitable for use with the multiple lasers needed for Dense Wavelength Division Multiplexing (DWDM). Non-linearity causes the generation of spurious interference crosstalk when several lasers are used with closely spaced center wavelengths. Dispersion shifted fibers are no longer commonly used and have been replaced by the newer Non-Zero Dispersion Shifted Fiber types.

- **Non-Zero Dispersion Shifted Fiber (NZ-DSF)**
  Non-linearities of the dispersion shifted fiber are greatly reduced by suppressing the zero-dispersion wavelength within the operational 1550 nm window. These fibers have uniform dispersion characteristics over a wide range of wavelengths in the 1550 nm window. NZ-DSF fibers can accommodate many different closely spaced lasers with reduced crosstalk interference between channels. Crosstalk in NZ-DSF fibers can be further improved in large-effective-aperture fibers by reducing the power density within the fiber. These enhanced NZ-DSF designs have large core size or mode field diameters and exhibit measurable performance improvements with DWDM systems for long distance links.

Single-mode fibers have the very broadest bandwidth, lowest cost, and lowest attenuation of any available optical fiber. Therefore, they are universally used in long-distance telephony and cable television applications.

Optical performance of fibers is relatively standardized in that the same optical characteristics may be found in fibers of the same type produced by several fiber manufacturers. The physical characteristics of the cabled fiber, however, are not necessarily uniform across the industry. The preservation of the fiber strength and its environmental performance are functions of the cable buffer materials and the cable structure. The multiple-layer tight-buffered system, if fabricated with the proper materials and technology, provides excellent physical, mechanical, and environmental protection for each fiber within the cable. It prevents the accumulation of moisture near the glass surface, which causes stress crack propagation and could ultimately cause fiber breakage. It also buffers or reduces the sensitivity of the fiber to repetitive small bends, referred to as "microbends", which cause an increase in fiber attenuation. The cable structure isolates and protects the fibers from the installation stresses and the installed environment.

Optical Cable Corporation has qualified all major fiber sources and, therefore, can incorporate any optical fiber into its fiber optic cable designs. The transmission system application will define the fiber type and fiber parameters required. The physical environment of the cable and the number of fibers required will determine the cable design most suitable for a particular installation. Please contact Optical Cable Corporation to discuss your fiber and cable requirements. Optical Cable Corporation can provide assistance in recommending the most suitable fiber optic cable products.