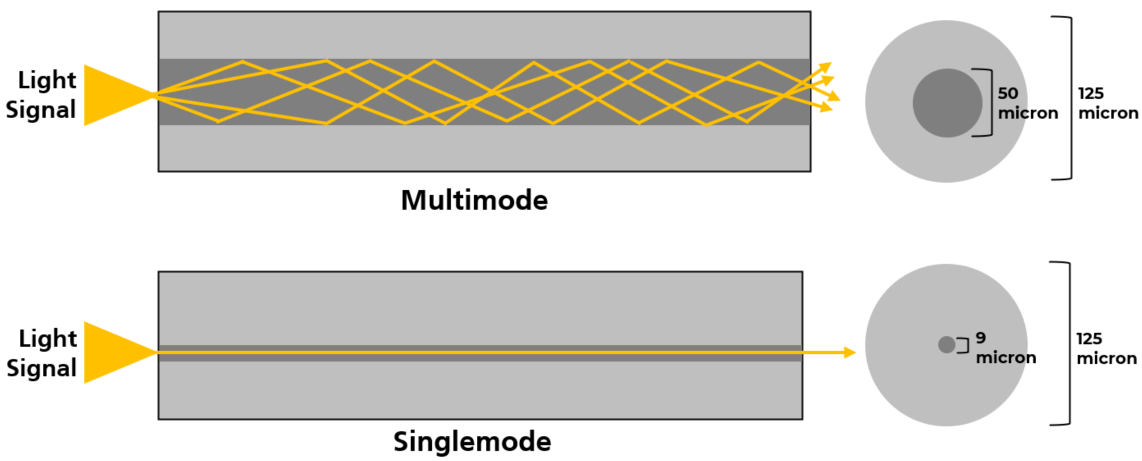
Fiber-optic cabling 101: The basics

Fiber-optic cabling is arguably the most vital component of global networks, comprising the links that connect equipment, buildings, campuses, cities, countries, and continents. Fiber offers virtually unlimited bandwidth, with the ability to transmit massive amounts over much greater distances than copper cables. Whether you're completely new to the industry, looking to grow your knowledge base, or gaining the skills necessary to design and install fiber networks, it all starts with understanding the fundamentals.

Multimode vs. singlemode—the core difference

In fiber optics, data is transmitted via pulses of visible light at specific wavelengths through a glass core that is surrounded by a 125-micron protective layer called the "cladding." The main difference between multimode and singlemode has to do with how light transmits and the size of the core. In multimode fiber, light signals travel via multiple modes, or paths, through a larger core—typically 50 microns. These modes reflect off the core-cladding boundary as they move along the length of the fiber. In a singlemode fiber, light signals travel in a straight line via one mode through a much smaller 9-micron core. In case you need a point of reference, the average size of a human hair is about 60 microns.



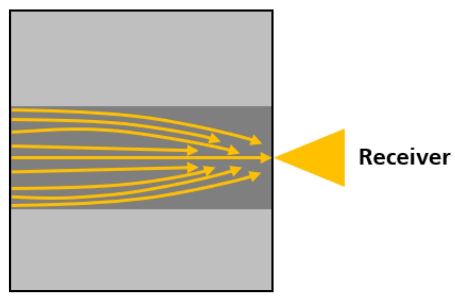
The transmission light sources for singlemode and multimode fiber also differ. While legacy multimode fiber used light-emitting diode (LED) sources and a larger 62.5-micron core, today's 50-micron multimode fiber uses vertical-cavity surface-emitting lasers, or VCSELs. These cost-effective lasers normally transmit at the 850-nanometer (nm) wavelength of light but may also transmit at the 953-nm wavelength. In contrast, singlemode light sources are higher-cost, higher-power lasers that typically transmit between 1310- and 1550-nm wavelengths. To increase bandwidth, light signals can also be sent over multiple wavelengths on one fiber, which is referred to as wave division multiplexing (WDM) technology—like increasing the number of lanes on a highway.

Multimode performance factors

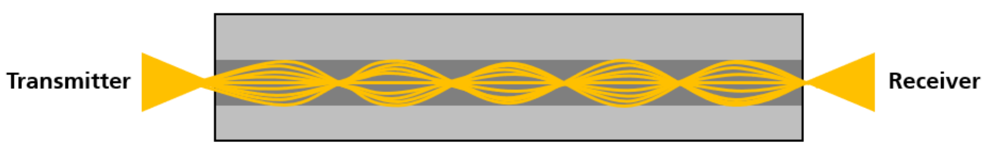
The amount of data that fiber-optic cables can send over a certain distance is referred to as "bandwidth." In both multimode and singlemode, bandwidth is limited by attenuation—the amount of energy a signal loses as it travels along a cable. Also referred to as "insertion loss," attenuation increases with length. If there is too much attenuation, the signal may not be strong enough to be deciphered at the receiving end. Because light signals travel differently through multimode versus singlemode fiber, there are different factors that also influence bandwidth.

In a multimode fiber, the modes of light travel at different speeds. Modes that travel near the center of the core (lower order modes) travel faster than modes that travel near the edge of the core (higher order modes). The difference in travel time between the fastest and the slowest mode is called differential mode delay (DMD). If DMD is too high, the receiver has difficulty deciphering the signal and, the longer the distance, the greater the DMD. That is why multimode fiber is limited to much shorter transmission distances than singlemode. For example, multimode fiber can transmit data at 10 gigabits per second (Gbps) to a distance of about 500 meters, while singlemode fiber can transmit data at 10 Gbps to a distance of 40 kilometers or more.

To control DMD, multimode fiber manufacturers grade the refractive index of the glass from the core to the cladding. The refractive index of a material determines how much light bends. If you've ever wondered why a straw looks bent in a glass of water, it's because air and water have different refractive indexes. Grading the refractive index from the core to the cladding causes light signals to travel in a parabolic curve—slowing down lower order modes and speeding up higher order modes to reduce DMD.



Differential Mode Delay (DMD) in Multimode Fiber

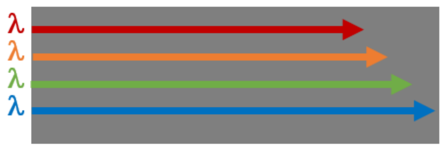


Graded Refractive Index Creates Parabolic Curve to Control DMD

Today's 50-micron multimode fiber bandwidth is measured as minimum effective modal bandwidth (EMB), which is calculated as megahertz over one kilometer (MHz-km) and is highly dependent on DMD. The improvement of DMD performance is what has allowed 50-micron multimode fiber to advance over time—OM3 multimode offers an EMB of 2000 MHz-km at the 850-nm wavelength, while OM4 and OM5 multimode offer 4700 MHz-km. With higher EMB, OM4 and OM5 can send more data longer distances than OM3. The main difference between OM4 and OM5 is that OM5 multimode has also been optimized for performance at the 953-nm wavelength to support WDM technology.

Singlemode performance factors

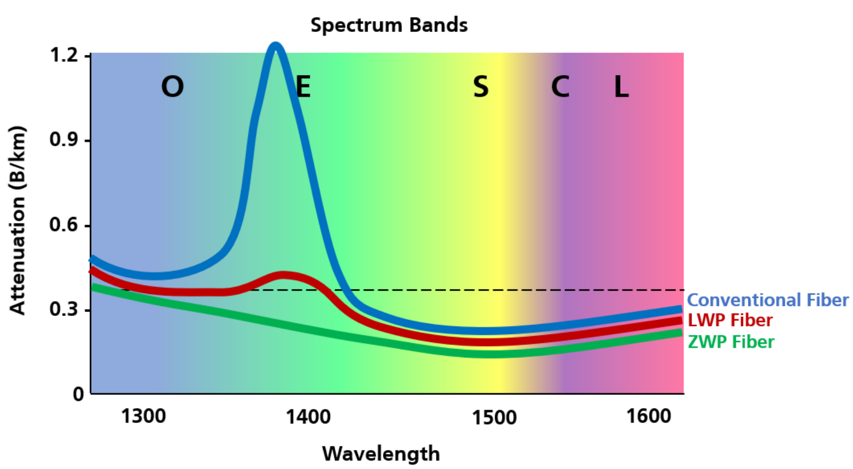
Singlemode fiber performance is not plagued by DMD, but that doesn't mean there aren't limitations. Light signals traveling down a singlemode cable can be subject to chromatic dispersion and polarization mode dispersion that cause random spreading out of the optical signal. These performance-limiting factors are caused by imperfections and asymmetries in the glass fiber core, and are more of a concern in long-distance, high-bandwidth links using WDM technology where light signals travel on multiple light wavelengths. Chromatic dispersion is different wavelengths traveling at different speeds, while polarization mode dispersion is different polarization states (X and Y axis) of wavelengths traveling at different speeds.



Chromatic Dispersion
Wavelengths traveling at different speeds

Polarization Mode Dispersion
Wavelength polarization modes traveling at different speeds

Another limiting performance factor for singlemode fiber occurs between the 1360- and 1460-nm wavelengths. Referred to as the "water peak" band, this E-band range of the wavelength spectrum tends to absorb hydroxyl ions and cause high attenuation. It is primarily a concern in long-distance fiber links using WDM technology that operates in this range. Over time, singlemode fiber manufacturers have successfully reduced signal loss within the water peak band—introducing low-water peak (LWP) OS1 singlemode and zero-water peak (ZWP) OS2 singlemode. OS1 fiber is still used for shorter-length links, while OS2 is primarily used in long-distance links.

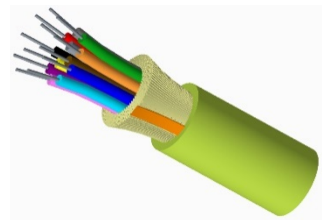


Types of cables

Multimode and singlemode fiber strands have a 200- or 250-micron protective outer coating that surrounds the core and the cladding. Fiber cables can contain a single strand or thousands of strands packed into multiple individual tubes, often with a center strength member. Basic fiber cable construction also includes strength members comprised of aramid yard (to protect the fibers during installation) and an outer protective jacketing.

Some cables may also feature a layer of steel armor for additional protection in industrial or outside plant (OSP) environments.

When it comes to fiber cable (unarmored or armored), there are primarily two types: tight buffered and loose tube. Tight-buffered cables feature a 900-micron plastic layer over the 250-micron protective coating and are primarily used for indoor applications, but they may also be rated for indoor and outdoor use for connecting buildings in a campus environment. Tight-buffered cables typically contain 288 fibers or less, with larger count cables containing individual tubes of 12 or 24 fiber strands.



In contrast, loose-tube cables contain bare 200- or 250-micron strands and have an overall smaller diameter. Loose-tube cables can contain more fibers and are therefore often used for indoor applications that require more than 288 fibers. They are also used in OSP environments using water-blocking technology that protects the cable from any water or moisture ingress. Some loose-tube cables can contain as many as 6,912 fibers, and higher count cables use ribbon fiber that features 12 or more fibers bonded together in a flat strip. These strips can be stacked together or rolled and packed into individual tubes. Higher count loose tube cables may also use 200-micron fiber strands to maintain a smaller overall cable diameter.

It's worth noting that fiber cable jackets and the fiber strands themselves are color coded per industry standards to help distinguish the diverse types. This is important since multimode and singlemode fiber cannot be mixed, and it is not desirable to mix different performances (e.g., OM3 and OM4). Individual fiber strands are also color coded to help ensure continuity throughout a link when connecting two fiber cables together.

Cable Type	Jacket Color
OM1 Multimode	Orange
OM3 Multimode	Aqua
OM4 Multimode	Aqua or Erika Violet
OM5 Multimode	Lime Green
OS1 Singlemode	Yellow
OS2 Singlemode	Yellow

Strand	Color	Strand	Color
1	Blue	9	Yellow
3	Orange	10	Violet
3	Green	11	Pink
4	Brown	12	Aqua
5	Slate	13	Olive
6	White	14	Magenta
7	Red	15	Tan
8	Black	16	Lime Green

So where are fiber cables used?

Now that we've covered the difference between multimode and singlemode fiber and the primary types of cables, let's take a look at the types of environments and spaces where fiber cables are deployed.

- **Premises LAN**—In the premises LAN environment, fiber-optic cables form the backbone infrastructure for connecting main equipment rooms and enterprise data centers to telecom rooms throughout a facility. Backbone LAN cables are typically tight-buffer cables containing 12 to 36 fiber strands. While both singlemode and multimode fiber can comprise LAN backbones, singlemode is becoming the preferred fiber type due to its greater bandwidth and longer distances. Fiber is also sometimes used in horizontal LAN infrastructure for specialty applications/devices and fiber-to-the-desk (FTTD), as well as for bringing fiber's bandwidth capabilities closer to the edge of the network.

- **Data center**—Due to its ability to support transmission speeds from 10 to 400 Gbps and beyond, fiber is the primary media for data center connections that need to carry massive amounts of information. Fiber connects service provider equipment to core switches and connects core switches to storage area networks (SANs) and equipment areas that house servers and other data center equipment. Data centers use a mix of singlemode and multimode, with large hyperscale and cloud data centers (e.g., Amazon, Google, Facebook) primarily using singlemode due to its distance and bandwidth capabilities. Multimode is typically used in enterprise data centers where links are shorter, but singlemode is becoming increasingly popular to meet ever-increasing bandwidth demands.

- **OSP**—In the OSP environment, fiber forms the backbone infrastructure between buildings in a campus environment. It is also used for long-distance fiber links from service providers' locations such as central offices and data centers, as well as for backhaul connections from cellular towers. Cables used in campus backbones could be tight-buffer or loose-tube multimode or singlemode fiber cables, while service provider fiber is almost always loose-tube singlemode cable that can contain hundreds or even thousands of strands.