Leading Optical Innovations

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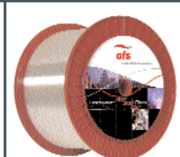

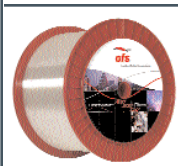

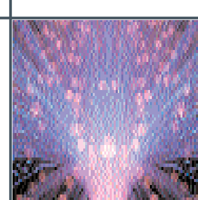

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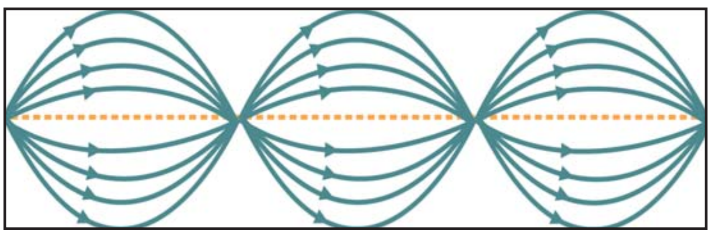
Since the introduction of Gigabit Ethernet, multimode fiber systems have been recognized as the lowest cost solution for high speed transmission over short reach optical communications, and this cost advantage continues for 10 Gb/s applications. How does one specify a multimode fiber for these high speed systems? The key fiber performance characteristic is bandwidth, or information-carrying capacity.

Bandwidth can be defined in a variety of ways depending on the application. As a result, there are several methods that fiber manufacturers use to ensure the bandwidth of their fiber. Understanding the differences between the various measurement techniques and associated definitions of bandwidth will help you make the best fiber choice for your applications.



Light travels through multimode fiber along different modes.

Maximizing Bandwidth for 10 Gb/s Ethernet

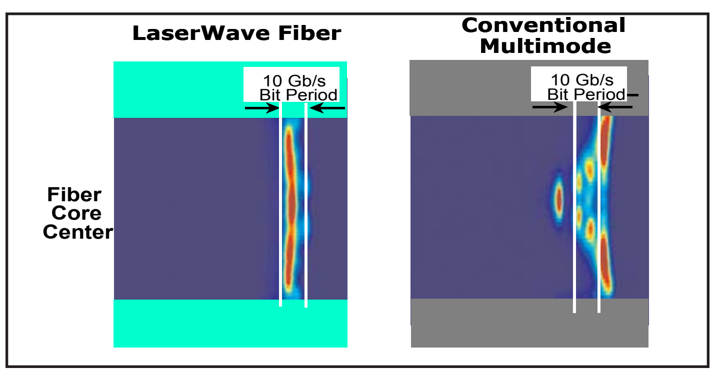
The recently published 10 Gb/s Ethernet standard supports the rapidly increasing demands of data networks. Originally, Ethernet technology transmitted data at speeds of 10 Megabits per second (Mb/s). Soon, a “Fast Ethernet” standard of 100 Mb/s was adopted. However, for high performance backbone applications, even this proved inadequate. The new network platform of choice for these applications became Gigabit Ethernet, and OFS introduced laser optimized GigaGuide® fiber in 1997 for these laser based systems. With the launch of OFS’ LaserWave™ fiber in 1999, network users now have the option of installing 10 Gb/s fiber in new networks. The standard for 10 Gigabit Ethernet specifying LaserWave 300 type fiber was published in 2002, and the same solution is specified for the upcoming 10 Gb/s FibreChannel standard for storage applications.

To specify any fiber for Gigabit Ethernet applications, the user’s first considerations must be bandwidth and transmission rate. The three standardized bandwidth specifications and measurements applicable to 1 Gb/s and 10 Gb/s are Overfilled Bandwidth, Restricted Modal Bandwidth, and Laser Bandwidth or EMB (effective modal bandwidth). In digital terms, bandwidth is expressed in a bit rate at which signals can be sent a given distance without one bit interfering with the bits before it or after it.

What might cause this interference? The answer lies in the way light travels through multimode fiber. When a pulse of light enters the fiber, it separates into different paths known as modes. Each mode is a self-supporting electromagnetic field that propagates axially along an optical fiber independent of all other modes. Light traveling in different modes can have different propagation speeds through the fiber. As the light pulse travels down the fiber, these modes spread out in time. This is known as modal dispersion.

The broadening of the pulse reduces the bandwidth of the system and can cause detection errors at the receiver. The difference in arrival time between modes within a pulse is known as differential mode delay (DMD). DMD is a direct measurement of the light transmission properties affecting bandwidth.

Manufacturers strive to maximize bandwidth by minimizing dispersion. This is done by controlling the precision and accuracy with which the fiber is designed and manufactured. For example, OFS uses its Modified Chemical Vapor Deposition (MCVD) process, which stringently monitors and controls the deposition and heating of ultra-pure chemicals in the layers of glass that form the fiber core.



Received pulse at 10 Gb/s over 300 meters. Red peaks (right) show how high dispersion causes each pulse to split into multiple, more disperse pulses.

This process, invented by OFS, enables precise control of the paths and the speeds at which the light travels. In fact, OFS technology controls even the difficult "center region" of the core in which many other processes struggle. Optimizing this "refractive index profile," as it is called, results in less dispersion (and, as a result, lower DMD) and greater bandwidth. Naturally, a DMD measurement method that can quantify the impact of refractive index properties on light transmission, and thereby bandwidth, is essential in the manufacture of multimode optical fiber.

For the user, it is the type of bandwidth and bandwidth measurement method used that should be the foremost consideration in the purchase decision. In order to provide the best assurance of performance, the optical fiber industry has developed increasingly sophisticated methods for measuring and ensuring bandwidth.

At the Source: LEDs and Lasers

Why has it been necessary to continually update the methods used to specify and measure bandwidth of multimode fiber? The reason is that the source of the light that transmits data through the fiber has evolved to support increasing transmission rates.

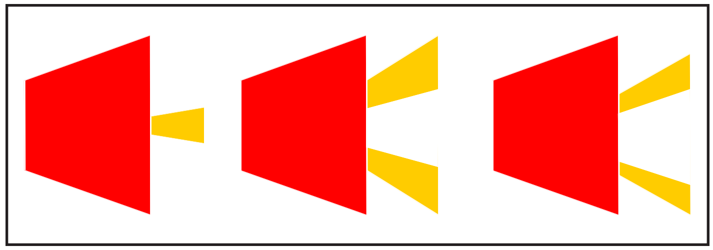
The traditional light source for standard and Fast Ethernet systems has been light-emitting diodes (LEDs), an excellent option for applications operating at or under 622 Mb/s. LEDs produce a smooth, uniform output that fills the entire fiber core and excites all its modes. To best predict the bandwidth of conventional multimode fibers when used with LEDs, the industry uses a method called Overfilled Bandwidth (OFL). As the name implies, this technique emulates LED performance by "overfilling" the modes of the fiber core to ensure that all modes are uniformly filled with light energy.

As transmission speeds increased to Gigabit Ethernet, however, it was found that LEDs were not a practical choice as a light source, for two reasons. First, LED sources typically suffer from high chromatic dispersion. Their light energy is transmitted in a broad band of wavelengths, and each wavelength travels at a different speed, resulting in pulse spreading. Second, it is not technically possible to modulate an LED one million times per second, as required by Gigabit Ethernet. In response, the industry developed high speed laser transmitters as a new light source.

The lasers used for Gigabit Ethernet applications are called Vertical Cavity Surface Emitting Lasers, or VCSELs (pronounced "VIK-suls"). Unlike an LED, the energy output of VCSELs is not uniform. It changes very sharply across the face of the output. As a result, lasers do not excite all the modes in a fiber, but rather a restricted set of modes. What's more, each laser fills a different set of light paths in the fiber, and does so with differing amounts of power in each path.

Given these differences, a new specification for bandwidth was created to emulate the operation with VCSELs. Laser Bandwidth, also know as EMB, defines the effective bandwidth of the fiber when used with a laser transmitter. As a result, a new technique was needed to measure bandwidth in laser-based systems. One method in use is called the Restricted Mode Launch (RML) method. RML tries to mimic a VCSEL by restricting the launch into one small section of the core and tests that part of the fiber.

But since each VCSEL can couple to different modes when used in the field, it's impossible to predict which group of modes should be tested. RML only provides an "average bandwidth": a measurement based on the excitement of an average number of modes defined by the launch. The process cannot measure independently the effect of individual mode groups and their interaction with the VCSEL energy pattern. In addition, there is no application standard (such as Ethernet or FibreChannel) that specifies the use of RML bandwidth. Therefore, the test will not necessarily replicate field conditions; it may, in fact, present a misleading measurement of the fiber's bandwidth in actual use.



At the same speed and wavelength, different lasers have different output profiles.

DMD: A Superior Method

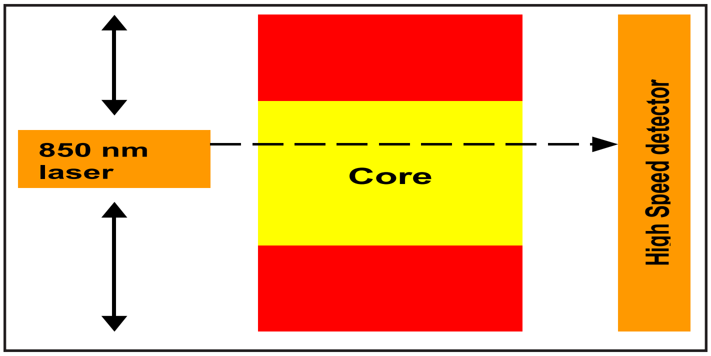
A superior method of ensuring bandwidth in Gigabit Ethernet fibers - in fact, the only measurement technique mentioned in the standards for 10 Gb/s speeds - is DMD. The DMD measurement and specifications were developed in conjunction with the transceiver specifications to ensure that the fiber would work properly with compliant transceivers in a 10 Gb/s system.

In DMD testing, high powered laser pulses are transmitted in small steps across the entire core of the fiber. Only a few modes are excited at each step, and their arrival times are recorded. The DMD of the fiber is the difference between the earliest and the latest arrival times of all modes at all steps. The lower the DMD, the higher the bandwidth of the fiber.

OFS has patented a method to mathematically derive the Laser Bandwidth/EMB of the fiber from the DMD information.
As with most specifications, the tighter the specification the more robust and reliable the product can perform. Within the 0-5 µm center of the fiber, OFS fibers provide even tighter DMD than is required by the standard. This results in higher reliability margins and improved performance with center-launch light sources. This is enabled by the OFS MCVD process, which tightly controls the center region of the refractive index profile.

The use of DMD measurements for verifying production multimode fiber was pioneered by Bell Labs and perfected by OFS Labs. The DMD measurement is currently the only reliable method for verifying bandwidth required for 10 Gb/s performance, because it is the only method that checks all modes across the fiber core independently. For that reason, industry associations such as TIA/EIA and ISO/IEC have published standards for DMD measurement and DMD specifications for laser-optimized multimode fiber.

Based on its pioneering work and standards leadership with DMD, OFS has successfully taken this method out of the development lab and into the production facility. During fiber manufacturing, DMD measurements are used to adjust the refractive index profile of OFS fibers to minimize differential mode delay.



To test a fiber's DMD, a laser is transmitted in one-micron intervals across the core.

In fact, OFS uses DMD testing to optimize all its laser-certified multimode fibers, including GigaGuide 50µm and 62.5µm 1 Gb/s fibers. And DMD is used to measure and qualify every length of LaserWave fiber to assure compliance to standards and more stringent OFS specifications. As required by TIA/EIA and ISO/IEC, the DMD of each fiber must pass a DMD "mask" specification that limits the DMD to assure the minimum EMB is achieved. These specifications were determined in TIA/EIA by modeling 40,000 VCSEL/fiber combinations and verifying the model with real world systems testing.

Meanwhile, the industry has developed an alternative DMD-based bandwidth measurement method called "calculated effective modal bandwidth" (EMBc). It combines the same high resolution DMD data that is used with the DMD mask specification, with power distributions of TIA-compliant 10 Gb/s VCSELs, to estimate the fiber bandwidth in the resulting system. Using the DMD data, EMBc essentially predicts the minimum bandwidth of each fiber for a given laser specification.

Specifying the Right Fiber for the Job

LaserWave fiber from OFS provides improved performance above the minimum required by the standards. The OFS MCVD manufacturing process eliminates the "center dip defect" that can plague fibers made with other processes. As a result, the DMD of OFS fiber is up to 60 percent better than what the standard allows. This helps ensure 100 percent system reliability to OFS rated link lengths at 10Gb/s. (Contact OFS for detailed fiber specifications.)

With this as background, the job of specifying the bandwidth of the multimode fiber you use is actually quite simple. For fiber used in your legacy LED based systems, the OFL method is perfectly valid as a measure of bandwidth. However, for fiber being installed in networks designed for 1 Gb/s speeds, the fiber must be laser-certified or DMD controlled to provide reliable performance in accordance with applicable specifications. For 10 Gb/s applications, a fiber whose laser bandwidth is assured using the OFS DMD method and specifications will provide the best, most reliable performance for your demanding network.

About the Author

Andrew Oliviero is Senior Product Manager for multimode fiber products at OFS. He has also served as Technical Manager of the Instrumentation and Measurement Engineering department of the company's Sturbridge, Mass. facility, where he was responsible for the development, implementation and control of fiber measurement equipment and processes.

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