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Measuring Bandwidth of High-Speed Multimode Fiber

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As 10 Gb/s transmission gains widespread use in data centers, high speed computing, and high-performance LANs, it's become clear that OM3/OM4 fiber (laser-optimized 50 µm multimode fiber capable of transmitting at 10, 40 and 100 Gb/s) is the best choice for cabling media.

Among the available fiber types, the optics used with multimode fiber are much less expensive than those used with single-mode fiber. What's more, OM3 and OM4 fibers are the only multimode fibers capable of supporting 40 and 100 Gb/s speeds.

Bandwidth performance and how it is ensured is arguably the most important consideration in selecting OM3/OM4 fiber. This paper explains the similarities and differences between two bandwidth measurements -- the Differential Mode Delay (DMD) Mask method and calculated Effective Modal Bandwidth (EMBc) -- to help the user make a more informed choice between these two industry-recognized techniques.

Evolution of Bandwidth Measurement

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

The traditional light source for standard and Fast Ethernet systems was the light-emitting diode (LED), 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 measurement method called Overfilled Launch (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.

A superior method of ensuring bandwidth in Gigabit Ethernet fibers - in fact, the only technique mentioned in the standards for 10 Gb/s speeds - is DMD.

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 suffer from high chromatic dispersion. 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 the Vertical Cavity Surface Emitting Laser (VCSEL) now familiar in the industry. Unlike an LED, a VCSEL produces an energy output that 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 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. 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. 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.

A superior method of ensuring bandwidth in laser-optimized fibers is DMD. In fact, DMD testing is required by the OM3 and OM4 fiber standards. The DMD measurement and specifications were developed in conjunction with transceiver specifications to ensure that the fiber would work properly with compliant transceivers for 10 Gb/s and beyond.

What the Standards Say

During development of 10 Gigabit Ethernet in the early 2000s, standards bodies determined how much Effective Modal Bandwidth (EMB) was required to transmit a given distance on laser-optimized multimode fiber. They determined that 2000 MHz-km EMB was needed to reach 300 meters (OM3) at 10 Gb/s, and that 4700 MHz-km would support 550 meters (OM4).

EMB is the *combined* bandwidth of the fiber and the VCSEL light source. Since the power output of VCSEL light sources differs from one to the next, a given VCSEL can produce different EMB on different fibers, and different VCSELs can produce different EMB on the same fiber.

To ensure a minimum EMB, TIA established specifications for VCSELs as well as fiber. These are contained in Detail Specification TIA-492AAAC and TIA-492AAAD, with international equivalents in IEC 60793-2-10. Any combination of VCSELs and fiber meeting the specs will produce the minimum required EMB.

These standards allow two ways to disposition the fiber: the DMD Mask method and the EMBc method. Both methods require DMD testing -- the difference lies in how the DMD data is used and interpreted.

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.

As with most specifications, the tighter the specification the more robust and reliable the product. 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 OFS' fiber manufacturing process, which tightly controls the center region of the refractive index profile.

DMD and EMBc: What's the Difference?

DMD measurement of production multimode fiber is currently the only reliable method for verifying bandwidth required for 10, 40 and 100 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 and ISO/IEC have published standards for DMD measurement and DMD specifications for laser-optimized multimode fiber.

The DMD Mask method directly compares DMD test results against a set of specifications (called templates and masks) to see if the fiber has the necessary performance. This is a straightforward graphical approach to make sure the data pulses do not spread excessively beyond the required 10 Gb/s bit period.

If the fiber passes these DMD specs, you can be assured it has the minimum EMB necessary no matter which VCSEL you use (as long as the VCSEL is compliant). The DMD mask technique is a simple and direct approach that provides the most reliable way to ensure that signals traveling in the fiber are well controlled over the entire core, or profile, of the fiber.

By contrast, the EMBc method takes the DMD results and matches them against a set of theoretical "weighting functions." These weighting functions, of which there are 10, are intended to represent the launch distributions of all compliant VCSELs.

The DMD results are combined mathematically with each of the 10 weighting functions. This produces 10 different EMBc values, the minimum of which is called minEMBc. The minEMBc value is then multiplied by a factor of 1.13 to obtain the fiber's EMB value. If this EMB value is > 2000 MHz-km (or 4700 MHz-km), the fiber is deemed OM3 (or OM4) compliant and should support the corresponding reaches at 10 Gb/s and beyond.

The EMBc method requires complex calculations to obtain a theoretical mathematical representation of the pulse in the time domain, which must then be converted into frequency space using yet more calculations. What's more, the weighting functions only represent a sampling of the launch characteristics of the many VCSELs that could actually be used.

Lastly, the EMBc method virtually ignores the center 0 - 5 μm (radial) region of a fiber's core. The rationale for this -- in theory, at least -- is that little power is supposed to be transmitted in this region for 850 nm 10 Gb/s and faster applications. In reality, larger amounts of power can be introduced into a fiber's center region from hot-center launch VCSELs, or from VCSELs that have been coupled off-center to the fiber.

Simply put, the EMBc method does not provide the same scrutiny of fiber quality and performance as the DMD Mask method. For these reasons, OFS recommends that you specify a fiber that has good control of DMD all the way to the very center of the fiber.

With this as background, the job of specifying the bandwidth of the multimode fiber you use is actually quite simple. For 10, 40 and 100 Gb/s applications, a fiber whose laser bandwidth is assured using the DMD Mask method and specifications will provide the best, most reliable performance.

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