Calculated effective modal bandwidth enhances 10-GbE reliability

Enterprise LANs should be designed to support legacy applications as well as emerging high-data-rate applications. Until recently, 62.5/125-micron (µm) multimode fiber has been the dominant fiber type deployed in the LAN, but the emergence of high-data-rate systems, such as 10-Gigabit Ethernet (10-GbE), warrants a migration to 50/125-µm laser-optimized multimode fiber.

Fiber bandwidth measurement techniques have evolved to ensure 50/125-µm laser-optimized multimode fiber will reliably support 10-GbE transmission. The most recently adopted method, minimum calculated effective modal bandwidth (minEMBc), enhances the 10-GbE reliability of 50/125-µm laser-optimized multimode fiber.

High data rate systems

The Institute of Electrical and Electronics Engineers (IEEE; www.ieee.org) approved the 802.3ae 10-GbE specification in June 2002. Guidance is offered for only one serial multimode fiber physical media-dependent (PMD) solution, 10GBase-S. The 850-nm serial PMD includes distances from 2 to 300 meters. The 850-nm wavelength is used for multimode fiber in response to the economic feasibility criteria of the IEEE 802.3ae task force.

As early as 1998, the TIA FO 4.2.1 working group discovered that high-performance laser-based multimode systems needed transceiver specifications alongside fiber measurements. For 10-GbE development, they were asked to define the optimal transceiver encircled flux launch conditions to correspond with the 50/125-µm differential mode delay (DMD) specifications, such that a 300-meter distance at 10-Gbits/sec could be obtained. Encircled flux is the percent power within a given radius launched by a transmitter into a multimode fiber core. For 10GBase-S, the encircled flux power distributions became ≤30% at 4.5-µm radius, and ≥86% at 19-µm radius.

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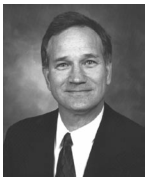
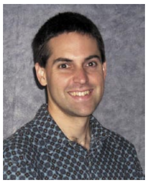
DMD measurement

In addition to specifying the encircled flux of the transceiver, TIA FO 4.2.1 used a DMD measurement procedure to ensure the required EMB of 2000 MHz·km. DMD is a fiber manufacturing measurement described in FOTP-220, where a singlemode pulse (≅5-µm spot size) is scanned across the 50/125-µm laser-optimized multimode fiber core in, at most, 2-µm increments. The resulting data captures the DMDs and mode-coupling power of a single fiber as a function of radial position.

From this DMD measurement, two methods of predicting EMB were standardized. The first, for translating DMD data into an EMB prediction, is the *DMD mask* approach, where the leading and trailing edges of each pulse are recorded and normalized in power relative to each other. This normalization approach reduces the raw DMD data to focus exclusively on time delay, where the overall fiber delay can be calculated by subtracting the slowest trailing edge from the fastest leading edge in units of ps/m.



To meet a nominal EMB target of 2000 MHz·km, a fiber must conform to one of multiple DMD templates, or masks. According to standards, a fiber meeting any of the mask sets will meet a minimum 2000 MHz·km EMB. Note that the DMD mask method provides only a pass or fail statement for the fiber.



EMBc methodology

The alternative method for predicting EMB from DMD is called *calculated effective modal bandwidth* (EMBc), which takes advantage of additional DMD data that the DMD mask approach neglects. As mentioned, the DMD measurement characterizes a single fiber's modal performance in high detail, including both modal time delay and mode coupling as a function of radial position.

To best predict EMB with this physical fiber data, something must be known about the laser with which it will eventually be paired. The laser might have power concentrated toward the center of the fiber (so-called "hot inside"), or away from the center of the fiber (so-called "hot outside"). In fact, it is most accurate to say that the laser's power distribution can fall anywhere with the standardized encircled flux boundaries described earlier.

This is where EMBc is advantaged: it is physically correlated with what happens in a real network.

The EMBc method combines a fiber's DMD data with representative laser sources spanning across a range of more than 10,000 standards-compliant VCSELs. EMBc then builds an output pulse for a series of fiber/laser combinations, and calculates EMB in units of MHz·km. Combining the source and fiber DMD measurements yields a synergistic method that accurately calculates the effective modal bandwidth of a 10-GbE system.

A system that satisfactorily works at 10 Gbits/sec needs to guarantee that it operates without failure for all cases. Some source manufacturers may tend to produce large-spot lasers, while others may produce small-spot ones, and the intent of the standards is to guarantee functionality for as broad a distribution of lasers and fibers as possible. The EMBc method provides a technique for using a specific fiber measurement (the DMD) and a specific laser measurement (encircled flux) to predict how any fiber will work with a set of lasers.

Referencing the VCSEL distribution, any fiber will have 10 different EMB values for each of these 10 sources. TIA-455-220A Annex D provides a procedure for simulating 10 different sources (spanning the entire range of permissible sources) and calculating the corresponding EMB value for each. Selecting the minimum calculated EMB value in turn guarantees that fiber's performance in the field with any acceptable VCSEL. For this reason, the second method of predicting EMB from DMD is often called minimum EMBc, or minEMBc.

In summary, the main purpose of the EMBc calculation is to ensure that a fiber's effective modal bandwidth will meet the 10-Gbits/sec requirement of 2000 MHz·km with any conforming laser. Further, the method provides a bandwidth value in units of MHz·km, which can, in turn, be used to design systems supporting 10-Gbit/sec performance beyond 300 meters.

EMBc's advantages

EMBc combines the properties of the source and fiber, and has many advantages compared to other bandwidth measurements adopted to date for guaranteeing a system's performance. Some significant advantages are:

1. **Sound physics base and experimental verification.** The EMBc process predicts source-fiber performance by integrating the fundamental properties of light sources with the multimode fiber's modal structure, which has been measured using a standardized DMD measurement.
2. **Ensures worst-case compliance.** The minimum EMBc used to specify the fiber performance ensures that the multimode fiber will work for all types of qualified sources, including, for example, the extreme hot centered and hot outside lasers. It is, therefore, a conservative and robust system-performance metric.
3. **Standards compliance and multi-vendor support.** EMBc is a method widely supported by many fiber, component, and system vendors. Broad consensus was obtained during its adoption into the TIA, IEC, and 10-GbE standards.
4. **Measurement scalability.** Since the EMBc method predicts fiber performance in scalable units (MHz·km), it can, therefore, be scaled to predict other bit rates and/or link lengths. Conversely, the DMD mask approach provides a pass or fail estimation around a nominal 2000 MHz·km, so it does not easily lend itself to predicting other EMB values.

A synergistic measurement method now exists that combines the source and fiber attributes to accurately predict 10-Gbit/sec performance for 50/125-µm laser-optimized multimode fiber. IT managers need to be certain the fiber being deployed today will reliably support a 10-Gbit/sec migration path over time.

The calculated effective modal bandwidth measurement procedure offers the newest and best performance guarantee for robust 10-Gbit/sec short-reach system transmission.