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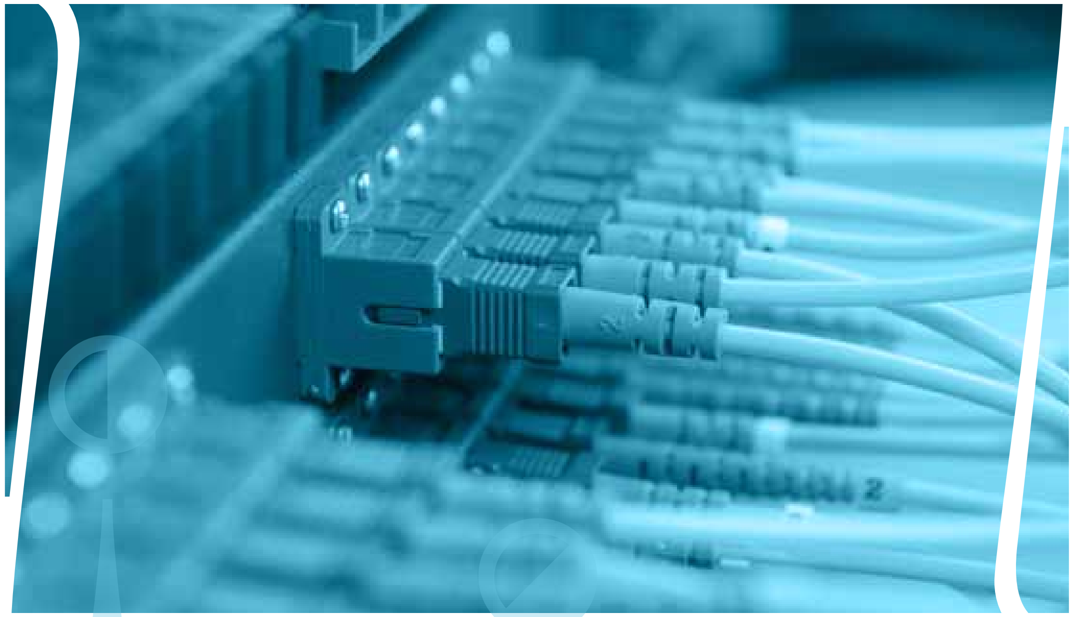

MULTIMODE
Optical Fiber Technology & Standards for Tomorrow's Data Centers

by John Kamino, RCDD

Managers of data centers and enterprise networks are trying to do their jobs in an ever-shifting marketplace, with nearly all the changes being driven by one word—bandwidth. Consider a few facts: Global Internet protocol (IP) traffic will quadruple from 2011 to 2016, reaching 1.3 zettabytes (1.3 x 1021 bytes) by the end of that period. By the same time, it is expected that 31 percent of that traffic will not be from personal computers. Incredible as it seems, the number of IP devices in use will be nearly three times the global population.

The applications driving this increase in traffic are familiar to all of us. On YouTube™, 72 hours of video are uploaded each minute, and an amazing four billion hours of video are watched a month. Meanwhile, Facebook has more than one billion active users. These are not just consumer applications. Today, smart businesses are using these channels to reach their customer base and provide up-to-the-minute information on a targeted basis.

Behind these applications are game-changing technologies like cloud computing, where providers offer a variety of services, including storage, software (i.e., software as a service [SaaS]) and infrastructure (i.e., infrastructure as a service [IaaS]). Applications such as Microsoft Office are now offered as a service/subscription-

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based option. Another growth driver is high-performance computing, where it is not unusual to see more than 6000 optical fibers coming out of a single rack.

The primary transmission medium recognized in the standards for these high-speed, high-bandwidth applications is optical fiber. Work on optical fiber and cabling standards continues at a feverish pace to support these demands. IEEE recently completed 40 and 100 gigabit-per-second (Gb/s) Ethernet transmission standards (i.e., IEEE 802.3ba) in 2012 and is already holding discussions about 400 Gb/s. Believe it or not, planning for terabit (TB) speeds will enter the picture sometime in 2015.

Optical Fiber Type

Optical fiber for data center applications is available in two major product types—multimode and singlemode. Multimode optical fiber, as its name implies, transmits light over many paths, or modes, through its core, which is much larger than a singlemode optical fiber core. The larger core of multimode optical fiber couples more light through the optical fiber. In short-reach applications like the data center, this allows for lower alignment costs and less expensive light sources, which can significantly reduce system costs.

The cost of 100 Gb/s singlemode optical fiber devices can be as much as 10 times higher than comparable multimode devices. However, for 10 Gb/s applications beyond 550 meters (m [1804 feet (ft)]) and 40 or 100 Gb/s applications beyond 150 m (492 ft), it is necessary to use singlemode optical fiber. With new choices available for singlemode optical fiber today, it is important to consider the options. For example, a bend-insensitive full spectrum singlemode optical fiber provides more transceiver options and more bandwidth, and it is less sensitive to handling of the cables and patch cords than conventional singlemode optical fiber.

Power consumption is becoming even more critical in today's data centers as link density and speeds increase. The C form factor pluggable (CFP) optical transceiver used with singlemode optical fiber consumes more than 20 watts (W), while a 120 Gb/s 12x small form factor pluggable (CXP) optical transceiver used only with multimode optical fiber consumes less than 5 W. For short-reach data center applications, that can save about 15 W of power per transceiver, plus an additional 15 W needed for cooling. The power savings increases significantly in a large data center with four transceivers per server (two on each end), multiplied by hundreds or thousands of servers. The CXP module also offers a small footprint. Sixteen CXP optical transceivers take up the same amount of space as four CFP optical transceivers.

Multimode optical fiber is typically referred to by the "OM" designations as defined in ISO/IEC 11801 and ANSI/TIA/EIA-568-C.3. OM optical fibers available today fall into several categories:

- OM1 for multimode optical fiber with 200/500 MHz-km overfilled launch (OFL) bandwidth at the 850/1300 nanometer (nm) wavelengths (typically 62.5 micron [µm] multimode optical fiber)
- OM2 for multimode optical fiber with 500/500 MHz-km OFL bandwidth at 850/1300 nm (typically 50 µm multimode optical fiber)
- OM3 for laser-optimized 50 µm multimode optical fiber having 2000 MHz-km effective modal bandwidth (EMB), also known as laser bandwidth, designed for 10 Gb/s transmission
- OM4 for laser-optimized 50 µm multimode optical fiber having 4700 MHz-km EMB, designed for 10, 40 and 100 Gb/s transmission

The difference between the various types of multimode optical fiber types is based on the two methods used to measure bandwidth—OFL and EMB. As shown above, OFL requirements for OM1 and OM2 multimode optical fiber are generally low at 200 or 500 MHz-km at 850 nm and 500 MHz-km at 1300 nm. OM1 and OM2 multimode optical fibers do not have a defined laser EMB requirement. For OM3 and OM4 multimode optical fiber, bandwidth requirements are significantly higher—especially in terms of minimum laser bandwidth, the key specification for today's applications.

The current version of ANSI/TIA-942-A, *Telecommunications Infrastructure Standard for Data Centers*, was published in August 2012. For multimode optical fiber, TIA-942-A specifies OM3 and OM4 and considers OM1 and OM2 obsolete. The standard also specifies LC connectors for simplex and duplex applications and the multifiber push-on (MPO) connector for multifiber applications. In addition, the standard has removed the 100 m (328 ft) length limit on horizontal links and now bases that requirement on specific applications.

Bend-Insensitive Multimode Optical Fiber

The latest discussions in the cabling standards bodies concern bend-insensitive multimode fiber (BIMMF). The fundamental difference between a standard multimode optical fiber and a BIMMF is the design of the core and the surrounding cladding. BIMMF has a "trench" just outside the core area that is not present in a standard multimode optical fiber. This trench provides improved macrobend loss by not allowing light to escape from the core. However, it also captures some light in the trench area, and this light is guided in so-called "leaky modes," which can propagate for considerable distances. It is important to ensure that these leaky modes are well understood and taken into account when measuring the performance of BIMMF.

BIMMF allows the installer to bend multimode optical fiber down to smaller radii. For example, at 100 turns around a 100 millimeter (mm [4 inches (in)]) radius, both standard optical and BIMMF have identical added loss requirements—no more than 0.5 dB of added loss at 850 and 1300 nm. We start to see a difference at two turns around a 15 mm (0.5 in) radius. Here, standard multimode optical fiber is allowed an added loss of 1 dB but a BIMMF is only allowed an added 0.1 dB of loss at 850 nm and 0.3 dB at 1300 nm. The difference becomes even more obvious at two turns around a 7.5 mm (0.3 in) radius, where standard 50 μm multimode optical fiber does not have a loss requirement, while BIMMF has a tight requirement of 0.2 dB at 850 nm and 0.5 dB at 1300 nm.

From a design perspective, the availability of this multimode optical fiber type means that manufacturers of cable management equipment, such as racks and enclosures, can redesign their equipment to take advantage of smaller bend radii. That can enable denser, more compact trays and shelves and improved air flow, while allowing shorter distances between the adapter face plate and the door front.

The standardization process for BIMMF is ongoing. Currently, a joint International Electrotechnical Commission (IEC)/Telecommunications Industry Association (TIA) task force is reviewing a number of important measurement procedures. This includes measurement of multimode optical fiber core diameter per IEC 60793-1-43 and the numerical aperture (NA) per IEC 60793-1-20. Both of these documents are expected to go out for ballot in April 2013. Another document expected to go out for ballot later this year is the IEC 60793-1-43 differential modal dispersion (DMD) measurement procedure for laser bandwidth. The key revisions will account for outer mode behavior. With BIMMF, it is very important to account for behavior of these outer modes, which was much less crucial for standard multimode optical fiber.

System Performance with BIMMF

In designing multimode optical fiber networks, three key parameters that impact system performance should be considered:

- Interoperability and connection properties
- Bandwidth
- Reliability

The goal in designing BIMMF must be to improve bend performance without compromising the three properties. One of the keys to achieving this goal is understanding the importance of matching core size and NA for low-loss connections, and the impact of the trench on these measurements.

Standard multimode optical fiber has no length dependence; in other words, a standard multimode optical fiber will have the same core diameter and same NA regardless of whether it is 2 m (6.5 ft) or 100 m (328 ft) long. This is not the case with BIMMF; a 2 m (6.5 ft) length of this type of multimode optical fiber will have a larger core diameter and higher NA than a 100 m (328 ft) length. In BIMMF, the outer modes can have a significant effect on short-length measurements. These modes do not have a chance to escape from the trench area in a short length of multimode optical fiber. Therefore, they "fool" the test into believing the core size and NA are much larger than they actually are. However, when measured over a longer length, these modes do escape and the true core diameter and NA are measured.

Studies show that matching long-length core diameter and

NA provide the best connection performance because the outer mode effect is minimized. A BIMMF with a nominal 0.20 NA and 50 µm core diameter measured using a 2 m (6.5 ft) sample length will have smaller nominal values than when a 100 m (328 ft) sample is measured. The importance of this is found when mating a long length of BIMMF to a standard multimode optical fiber. For 300 m (984 ft) of the BIMMF described (e.g., 0.20 NA and 50 µm core diameter), there would be a higher loss than expected when mated to a standard multimode optical fiber, because the actual NA and core diameter values would be lower than nominal. This was a key discovery of work done on BIMMF and has led to proposed revisions to the measurement methods.

Bandwidth is a critical performance factor in system performance, and bandwidth measurements can be deceiving. Consider two multimode optical fibers (A and B) that have virtually the same EMB calculated (EMBc) measurement. However, the profile of multimode optical fiber A shows significantly wider pulses in the outer modes. Also, multimode optical fiber A has higher OFL than multimode optical fiber B. This is because OFL considers the behavior of all the light traveling in the optical fiber, including the light in the outer modes. EMBc measurement disregards those outer modes, resulting in higher laser bandwidth. What effect does this have on system performance? Optical fiber A has a 1.3 dB penalty over a 550 m (1804 ft) 10 Gb/s link. Optical fiber B has more than 3 dB and exhibits lower performance than optical fiber A. For this reason, a proposal in the new standards calls for the use of calculated OFL as a guideline for screening potentially problem multimode optical fibers.

The final parameter to consider is reliability—not only *optical* but also *mechanical* reliability. Optical reliability is simply a function of maintaining the signal through the link. BIMMF helps you do that with its small diameter bends, but it does not help with mechanical reliability. You will sometimes see illustrations of an optical fiber jumper sharply bent over a shelf edge with a very small bend radius of 1 to 2 mm (.04 to .08 in). A bend radius this small is likely to adversely affect the usable life expectancy of the optical fiber. Therefore, bend-insensitive fiber is *not* a substitute for proper installation procedures.

Application Standards Continue to Evolve

Short-reach networking applications in the early 1990s were in the range of 10 Mb/s, and light was transmitted using light emitting diodes (LEDs). The move to gigabit speeds required the use of vertical cavity surface emitting lasers (VCSEL). This made 10 Gb/s achievable in 2002 and 2003, and we have now progressed to 40 and 100 gigabit Ethernet utilizing the higher laser bandwidth of OM3 and OM4 multimode optical fiber.

With the transition to 40 and 100 Gb/s Ethernet, the industry is moving from serial transmission (i.e., one optical fiber transmitting and one optical fiber receiving) to an eight-fiber link for 40 Gb/s (i.e., four optical fibers transmitting at 10 Gb/s and four optical fibers receiving) and a 20-fiber link for 100 Gb/s (i.e., 10 optical fibers transmitting and 10 optical fibers receiving). Connector interfaces are also evolving, with 40 Gb/s using a 12-fiber MPO connector, with four optical fibers sending the light signal and four receiving. This is often referred to as "4x10." A 12-fiber cable is typically used, but the optical fibers installed in the center four positions of the connector are unused. For 100 Gb/s, several different implementations are possible. The preferred option calls inside for a 24-fiber MPO connector (i.e., two rows of 12 optical fibers), using the inner 10 optical fibers of each row with each operating at 10 Gb/s (i.e., 10x10 transmission).

The data center environment is migrating to 10 Gb/s links on servers. Uplinks from the server switch are migrating to 40 Gb/s over OM3 and OM4 multimode optical fibers, with expectations that 100 Gb/s deployments will begin soon. This is driving significant demand for larger optical fiber count cables. For next generation Ethernet, there is a good deal of discussion about using a 100 Gb/s 4x25 design (i.e., four optical fiber transmitting at 25 Gb/s and four optical fibers receiving) rather than using the current 10x10 implementation. The lack of interest in supporting a 24-fiber channel 10x10 system is due in part that it significantly increases the amount of optical fiber that needs to be installed. A 4x25 design could re-use the same cabling currently used for 4x10 for 40 Gb/s, requiring no additional cable.

IEEE held a Call for Interest (CFI) for 400 Gb/s Ethernet in March 2013, with the expectation that the effort would move forward to Study Group status. Fibre Channel standards are also evolving. In fact, 32 Gb/s Fibre Channel is expected to go to ballot for approval later this year, and 128 Gb/s Fibre Channel is under discussion. The demand for ever-higher speeds is expected to continue unabated. ■