PERFORM BEYOND EXPECTATIONS

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Optical Fibers, Transceivers and Connectivity – A New Perspective

The TEK Center
TECHNOLOGY • ENGINEERING • KNOWLEDGE

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Introduction

The capacity of local area networks and data centers is growing at an unprecedented rate. Fiber optic infrastructure has been the backbone for these communication networks for the past thirty years. Multimode fiber (MMF), which has been the preferred choice of backbone in these networks, has seen various iterations over time, evolving from carrying megabits per second to tomorrow's 400 Gigabits per second or more.

Advancement in communications over MMF was made possible by three key components of technology – lasers, fibers and connectivity. Early MMF links used Light Emitting Diodes (LED), but the invention of Vertical Cavity Surface Emitting Laser (VCSEL) at 850 nm not only increased the capacity of the links by many times, but also made MMF links very cost effective. Most, if not all, of today's short reach transceivers use 850 nm VCSELs in them. The fibers were also optimized after the introduction of VCSEL, and the 'laser optimized' 50 µm core diameter fibers had higher bandwidth and greater capacity compared to the legacy 62.5 µm fibers. As the line speeds for MMF links changed from 1G to 10G, parallel transmission over multiple fiber strands and array connectors further increased the speeds by 10 times. Today's 40G and 100G MMF links use four or ten fibers in each direction. The compact MPO connector, which mates either 12 or 24 fibers, not only enabled the capacity growth, but also increased density and facilitated the speedy installation of MMF links in today's data centers.

As we move forward with new 25 Gb/s lane speeds and multi-fiber connectivity to reach up to 400 Gb/s capacity in the near future, we are rapidly approaching the practical capacity limits for VCSEL and current MMF. On the other hand, increasing the density of parallel transmission is becoming more laborious and therefore less cost-effective. All of this creates a challenging problem for MMF to sustain the capacity growth of the future. A new kind of fiber called wideband MMF is currently being developed, aimed at increasing the capacity of MMF by a factor of four by enabling wavelength division multiplexed transmission. As an example, the new fiber can provide bandwidths of 100G with only two fiber strands, each carrying four wavelengths, instead of the eight fibers that are required today. Wideband MMF ensures that the capacity of MMF links not only continues to increase, but also supports existing and emerging applications.

Multimode Fibers: A Brief History

Early multimode fibers with both 50 µm and 62.5 µm diameters were considered for deployment in enterprise, telephone and FDDI (Fiber Distributed Data Interface) networks. The 62.5 µm fiber, also known as OM1 was preferred due to its robustness to connector mis-alignments compared to the 50 µm fiber. Early communication links had very small capacity and limited reach. As demand increased, and alignment techniques, optical sources and detectors improved, SMF-based links became predominant for longer distances and higher capacities. MMF, which had inherent cost advantages due to its alignment robustness and cost-effective optical devices, was mainly applied to enterprise LAN and similar applications.

As network capacities increased to the 100s of Mb/s, a new higher bandwidth MMF was standardized with a 50 µm core diameter in early 1990s. This 50 µm MMF fiber, called OM2, had similar tolerance to misalignment as OM1, but with higher bandwidth. During the same period, VCSELs became the predominant laser technology for MMF links and replaced LEDs. Both OM1 and OM2 were suitable for data transmission from 1 Mb/s to 1 Gb/s, but had very short reach for 10 Gb/s links. 10GbE applications created a need for laser optimized MMF with enhanced bandwidth, and the first laser optimized MMF, called OM3, developed in late 1990s was able to deliver up to 300 meters of 10 Gb/s data.

In 2003, realizing that the trend of increased data demand would continue, Berk-Tek launched its GIGAlite™-10XB fiber, which became known as OM4+. Although GIGAlite-10XB was launched well ahead of OM4 (agreed upon by the industry in 2009), it earned the "+" because it had a higher modal bandwidth than OM4 (4900 MHz.km versus 4700 MHz.km) and was able to provide 600m link distance for 10 Gb/s.

Figure 1 shows various MMF grades, their bandwidth at 850nm, and the maximum transmission distance for 10GbE and 40/100 GbE. An engineered link with GIGAlite-10XB can reach twice the distance compared to the standard OM4. This becomes especially important as data centers become larger and more dense, with more and more hops and distance between network equipment. When considering the power budget of a channel, a trade-off exists between maximum distance and connector loss. Increasing the length of the channel decreases the number of connections you can have without affecting operation. Conversely, the more connections a channel has, the shorter the transmission distance will be. This trade-off exists due to 1) the limited power budget of the transceivers in the link (lasers, detectors, etc.), and 2) the bandwidth of the cable.

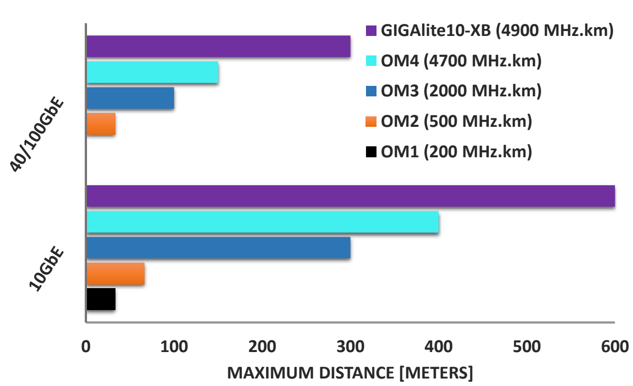

Figure 1: *Maximum transmission distance for 10, 40 and 100 Gb/s Ethernet for various types of MMF and their respective bandwidth distance products.*

Data Center Managers are continuously challenged by increasing density and scale in their data centers. They can optimize their power budgets by selecting cable and connectivity solutions that allow greater distance or increased connector counts beyond what is specified by the standard. This can be achieved by using higher bandwidth cables and/or optimized transceivers, which provide additional power budget to spend on increased distance or connector loss. In other words, you can go further and add more connections without sacrificing performance.

Figure 2 shows a comparison of power budgets for a 40GBASE-SR4 link using OM3 versus Berk-Tek GIGAlite-10XB fiber.

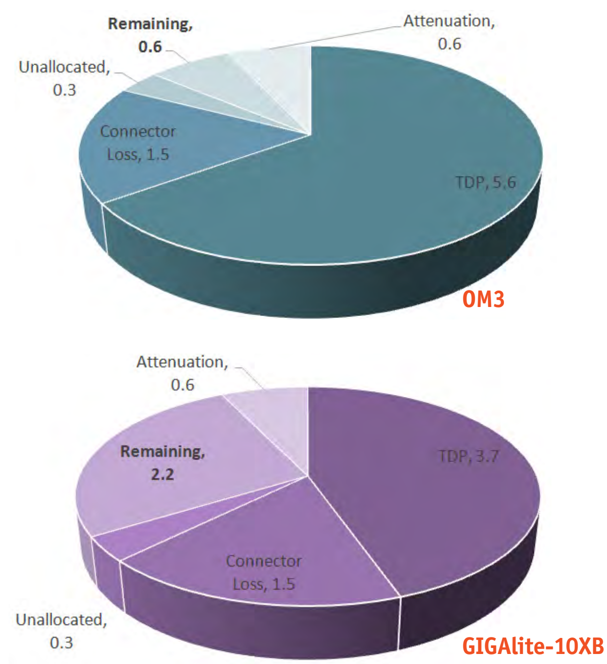

Figure 2: *Comparison of power budgets and allocations of a 40GBASE-SR4 link using OM3 and Berk-Tek GIGAlite-10XB.*
1.6 dB of power budget can be gained by using GIGAlite-10XB.

Connectivity

Earlier enterprise LAN and data center connectivity were mostly 1Gb/s to the server and 10 Gb/s between the switches. As speeds and density increase, 40 and 100 Gb/s links rely on parallel optics and connectivity. Currently there are two parallel optics schemes: one that uses eight fibers and one that uses 20. 40GBASE-SR4 and 100GBASE-SR4 use a 12-fiber MPO connector with a set of four fibers in each direction and four fibers unused. The 100GBASE-SR10 uses a 24-fiber (two rows of 12 fibers) MPO connector, where 10 fibers in each direction carry 10 Gb/s data each, and four fibers are unused. 16-fiber and 32-fiber variants of MPO connectors are currently being developed for higher speeds.

That said, most of the data centers that use 1G/10G have only duplex LC connector based infrastructure, and any upgrade in capacity would require multi-fiber connectivity. Many data centers and enterprises have migrated to 40 Gb/s using 12-fiber MPO based infrastructure. The disadvantages with this path are that 33% of the fiber is unused, and migration to 100GBASE-SR10 is not possible since it requires 20 strands of fiber. A cabling infrastructure with a base of 24-fibers is highly recommended. The 24-fiber base can be used for a 100GBASE-SR10, for three 40/100G-SR4, or for twelve 10G connections. The 24-fiber installation also supports the new non-standard LC duplex-based 40 Gb/s connections.

Optical Transceivers

Optical transceivers are the key building blocks for all network connectivity both inside and outside the data center. A transceiver is a small pluggable form factor opto-electronic device, which plugs into a server or a switch. The optical cable is then connected to it. Most of the transceivers that populate the networking equipment in a data center carry either Ethernet or Fibre Channel traffic. **Figure 3** shows the evolution of Ethernet technologies. Gigabit Ethernet was released in the late 1990s, and the technology rapidly moved to 10 Gb/s in 2002 with 10GbE. Based on the 10 Gb/s optical line speeds, the short reach variants of 40 and 100 Gb/s Ethernet standards were developed in 2010. These short reach 40 and100 GbE use four and 10 lanes of 10 Gb/s each, respectively. At the same time, the long reach variant of 100G was developed using 4x25 Gb/s CWDM optical channels, and the technology was named 100GBASE-LR4. In early 2015, a new version of 100 GbE over MMF, which uses 25 Gb/s optical lanes, was standardized. This was named 100GBASE-SR4.

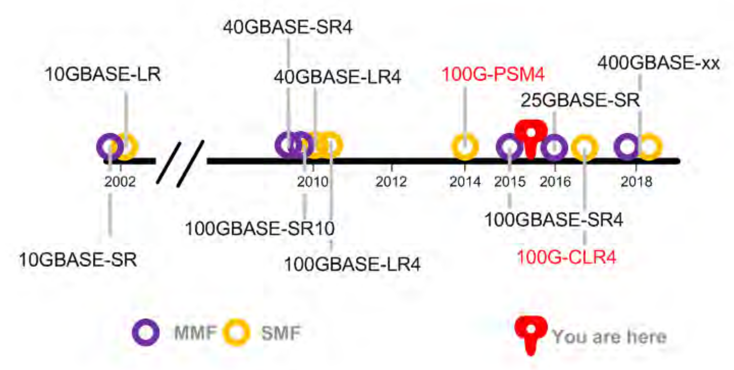

Figure 3: Ethernet Roadmap

Currently, several other standards are being developed. A 400 GbE standard to cater the switch-to-switch traffic is underway. For short reach, 16 lanes of 25 Gb/s multimode channels are being considered. And for the longer reach single mode fiber, there are several options, which use a combination of parallel optics and wavelength division multiplexing. Recently there is also interest in developing 50 GbE and subsequently a 200 GbE technology. Other efforts to make cost-effective single mode transceiver technology for short range between 500 meters and 2 kilometers are under consideration. Advances in ASIC (Application Specific Integrated Circuit) designs and integrated photonics will fuel future transceiver technologies.

The Anatomy of a Transceiver

Ethernet is comprised of seven network layers, as illustrated below in **Figure 4**. Layer 1, referred to as the Physical Layer (PHY), is where the transceiver and medium (optical/copper cable) reside. The PHY can be divided into two sub-layers: Physical Media Independent (PMI) and Physical Media Dependent (PMD). The PMI, which typically consists of coding and signaling (PCS, PMA, etc.), resides on the host (server or switch), whereas the PMD, which determines the physical media and reach, resides in the transceiver.

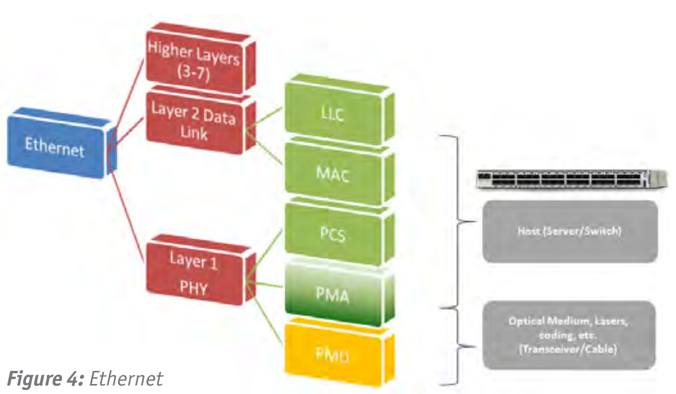

Figure 4: Ethernet and the OSI Model

As the name suggests, the PMI is independent of the medium used. For example, in a 10G port of a network switch, the PMI which consists of PCS, PMA and other higher network layers, will be identical for both 10GBASEE-SR and 10GBASE-LR. The PMD part, which is the transceiver, however, does differ for 10GBASE-SR and 10GBASE-LR, and plays an important role in the reach that a link can achieve. **Figure 5** shows the anatomy of the PMI and PMD.

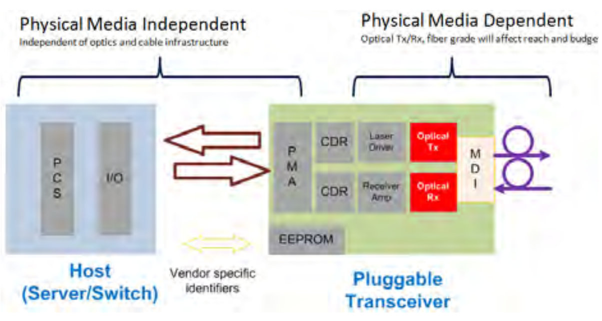

Figure 5: PMI and PMD Anatomy

A 10GBASE-SR PMD consists of multimode VCSELs, detectors, laser drivers and receiver amplifiers. Various properties of the components, in conjunction with the properties of the medium used, will ultimately determine the link performance. In essence, the choice of transceiver affects the cabling infrastructure and physical design of a data center more than its networking and architecture.

For cable, parameters such as fiber bandwidth, and connectivity loss determine the power budget and reach. For a transceiver, the parameters that determine the budget are transmission power, receiver sensitivity, signal rise, fall times and jitter. Typically, the minimum transmission distance of a technology platform is determined by the worst case values of all the above mentioned parameters. The power budget of a link can be increased significantly by adjusting a few of them.

In **Figure 6**, we see how transceiver parameters affect link performance. Each of the blue bars represents the percentage increase in reach that can be achieved by changing just one transceiver parameter. For example, choosing a transceiver with better VCSEL spectral width – even if we change nothing else – can increase by more than 30%. The purple bar represents the nearly 20% increase in reach that can be achieved by selecting a high bandwidth fiber such as GIGAlite-10XB. When we combine these changes by optimizing more than one parameter in the transceiver and selecting a high bandwidth fiber such as GIGAlite-10XB, we see a very significant increase in reach. By doing this, the reach of a 40 GbE short reach link can be easily doubled, and up to 500 meters of transmission can be achieved, as depicted by the green bar.

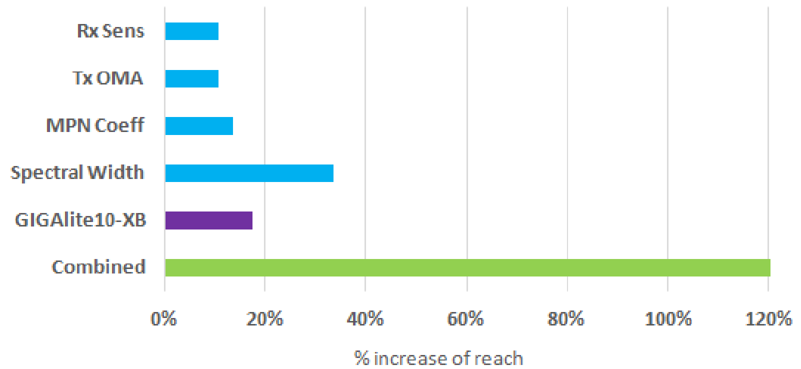

***Figure 6:** Percentage of increase in transmission distance of a 40 GBE link by engineering the transceiver and cable parameters.*

Conclusion

Networking and communication technology is going through a fast paced evolution, and technologies are changing every three to five years. Multimode fiber not only provides a cost-effective solution for network connectivity, it renders itself relevant for 400 Gb/s and above links. Multimode fiber has evolved, with the highest current bandwidth fiber enabling a seamless migration to greater speeds. For future-proof installations, wideband MMF can serve up to a 1.6 Tb/s link. Using a combination of the highest bandwidth fiber, and an optimal transceiver and connectivity, can ensure a robust data center that will stand up to the future demands that will be placed on it.

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This stamp certifies that all testing was performed, reviewed, and approved by highly trained, experienced engineers dedicated to studying and developing solutions for future network infrastructures.

Located in New Holland, Pennsylvania, The TEK Center at Berk-Tek is comprised of several labs and a technology showcase. By employing industry-leading research, advanced testing procedures, and sophisticated modeling for emerging technologies, the applications and system labs translates expanding network requirements into leading edge cabling solutions that perform beyond the standard. Similarly, to exceed your expectations in real world applications, the materials lab develops advanced proprietary materials and process technologies that result in superior application performance that you can see and hear. The technology showcase displays the results of these labs along with industry-available equipment shown in actual segment usage, such as data center, security, and enterprise spaces. The TEK Center is a part of an extensive global R&D network with similar laboratories found throughout Nexans Inc.

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