COMMSCOPE®

The fundamental differences between OM5 and OM4+ fiber

Pressure continues to build for data center operators to migrate to faster applications and longer link distances. In response, infrastructure OEMs and industry standards bodies are working overtime, developing the necessary link components and performance guidelines.

EXECUTIVE SUMMARY

Typically, the introduction of a new technology involves engineering and testing, which leads to initial market interest and standards development. Having standards in place prior to wide-scale deployment is preferred as it ensures aspects such as performance specifications and application support are clearly articulated using industry-accepted standards—but this is not always the case.

In 2016, the industry recognized and standardized wideband OM5 multimode fiber (MMF) and is now deploying it to enable improved support for applications involving multiple wavelengths. Some, however, now claim that proprietary variations of OM4 (so-called OM4+) are roughly equivalent to OM5 in supporting technologies like BiDi and SWDM4. They argue that OM4+ can support existing 850 nm applications over longer distances than OM4 or OM5. These assertions are based on a purportedly higher calculated effective modal bandwidth (EMBc) or the purported effects of chromatic dispersion compensation.

On the surface, such claims may appear to suggest that OM4+ is equal to or, in some cases, superior to OM5. However, the analysis is based upon nonstandard measurements and performance claims. Accurately comparing the two technologies can be difficult and confusing.

This paper will look at the stated performance differences between OM4, OM4+ and OM5 and evaluate the performance claims. Specifically, we will consider optical transmission design, inter-symbol interference and the concept of chromatic dispersion compensation as they relate to supporting higher data rates in data center applications.

This paper will look at the stated performance differences between OM4, OM4+ and OM5 and evaluate the performance claims. Specifically, we will consider optical transmission design, inter-symbol interference and the concept of chromatic dispersion compensation as they relate to supporting higher data rates in data center applications.

BRINGING NEW TECHNOLOGY TO MARKET

During the past 30 years or so, the evolution of multimode fiber-optic cabling for the data center has followed a fairly methodical process. Standards organizations—with representation from design and manufacturing experts—develop initial product design and proof of concept, and eventually draft and adopt industry standards that define inter-operable systems. Alternatively, a group of manufacturers may work to define proprietary multisource agreements (MSAs) that establish performance requirements and supportable distances for specific components, like optic transceivers.

To ensure data center operators and component manufacturers are all working from the same set of industry-accepted fiber performance specifications and definitions, the vetting process of standardization is very beneficial. Optic transceivers are designed and specified to work with various standardized optical fibers. When these standards are followed, data center operators can be assured the overall application will function as expected. As a proprietary technology, OM4+ cannot provide such assurance because its specifications are not recognized by any optical fiber standards body. This prevents OM4+ from being referenced by application standards bodies like IEEE 802.3 for Ethernet and INCITS/T11 for Fibre Channel. As a result, OM4+ does not enjoy the same support from active equipment vendors as does standardized OM5.

Conversely, OM5 has gained recognition in emerging standards for Ethernet at 50 Gbps, 100 Gbps, 200 Gbps and 400 Gbps, and the emerging 64G fiber channel. A comparison of key performance metrics is shown in Table 1. Notice the OM5 metrics at 953 nm that are not specified for OM4.

TABLE 1: COMPARISON OF KEY PERFORMANCE METRICS BETWEEN OM4 AND OM5

PARAMETER	OM4	OM5
Effective modal bandwidth at 850 nm, min (MHz*km)	4700	4700
Effective modal bandwidth at 953 nm, min (MHz*km)	Not Specified	2470
Chromatic dispersion at 840 nm, max (|ps/nm*km|)	108.4	103
Chromatic dispersion at 953 nm, max (|ps/nm*km|)	65	61.7
Cabled attenuation at 953 nm per 568.3-D, max (dB/km)	Not Specified	2.3

OPTICAL TRANSMISSION DESIGN

To compare the benefits of OM4, OM4+ and OM5, we first need to review the objectives of optical link designs. To ensure an optical fiber transmission system will operate with advertised low incidence of transmission errors, it is necessary to establish and adhere to an optical power budget. A properly designed system provides sufficient gain to overcome the impairments in the channel. The example shown in Figure 1 illustrates the IEEE optical link power budget model for 25G and 100G (i.e. 4×25G parallel) Ethernet over MMF cabling.

The power budget starts at the top of the stack, with the transmitter's minimum modulation launch power. It ends at the bottom of the stack with the receiver's maximum permitted sensitivity required to yield an acceptable operation of the link.

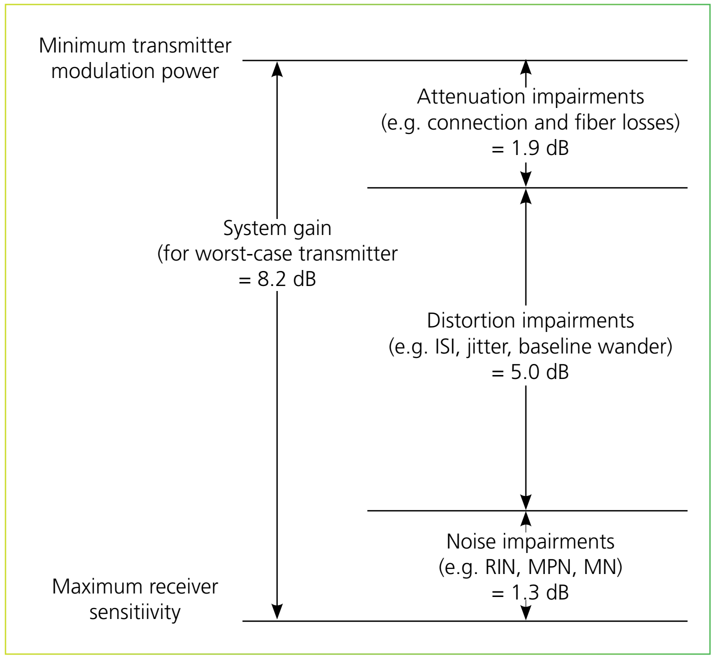

FIGURE 1 – Typical power budget for 25G and 100G Ethernet over MMF

In between are the channel impairments that must be overcome in order to close the budget without deficit. These impairments include:

- Signal attenuation through connections and fiber
- Distortion impairments from inter-symbol interference (ISI), jitter and baseline wander
- A variety of noise impairments such as mode partition noise (MPN), relative intensity noise (RIN), and modal noise (MN).

The distortion impairments consume the largest fraction of the power budget, leaving relatively little allotment for attenuation effects before channel reach reductions must be imposed. This loss budget must be carefully managed to preserve useful link distances while allowing for channel topologies with patching capability that larger data centers require for reconfiguration and administration agility and scalability.

A properly engineered solution takes the various signal impairments into account and provides specific design guidance to support the application. The entire end-to-end budget analysis can be expressed as channel topology limits that specify the supportable channel length as a function of the number and type of connections within the channel. Examples of such topology limits are shown later in Table 3 and 4.

INTERSYMBOL INTERFERENCE (ISI)

ISI is caused by the combined limited bandwidth of the transmitter, fiber and receiver and is often the largest single impairment in an MMF transmission channel. During data transmission the channel's bandwidth limitation causes the discrete pulses of light to spread out in time. Energy from one bit falls into the time slots of adjacent bits, reducing the amplitude differences between the bits. This reduction is the ISI impairment.

There are two main causes of ISI: modal dispersion (MD) and chromatic dispersion (CD). MD is caused by the differences in propagation velocity among the various modes, or paths, through which light may travel inside a MMF. It is measured using a standardized differential mode delay (DMD) method in which pulses of light are selectively launched into different modes of the fiber by changing the launch position of the measurement laser. Pulses are collected at the output of the measured fiber and plotted against their respective radial launch position to form a composite view of all the mode delays. Figure 6 illustrates examples of DMD plots for the same fiber at different wavelengths.

CD is caused by differences in propagation velocity of different wavelengths injected into the fiber from the transmitter. CD is measured using standardized CD methods in which light pulses of different wavelengths are launched into the fiber and the differences in propagation times are collected and plotted against their respective wavelength. Unlike MD, which can vary widely from fiber to fiber, CD is relatively consistent for a particular fiber design. For the wavelengths used in MMFs, shorter wavelengths travel more slowly than longer wavelengths.

All laser-optimized MMF—such as OM3, OM4 and OM5—have specifications that limit MD and CD. The primary difference between these OMx grades of fiber is their minimum EMB, which is calculated from the DMD data that measures MD. Higher EMB requires lower MD.

There are three standard techniques for reducing the ISI impairment generated within MMFs.

- 1)) Reduce MD to raise EMB per unit length. Depending upon the application's wavelength, this can be equivalent to using a higher version OMx cable.
- 2) Shorten the channel length to reduce total dispersion. This is why the reach of OM3, for example, is shorter than OM4.
- 3) Increase the transceiver bandwidth by speeding up the transmitter using newer technology, and widening the receiver bandwidth with faster and lower noise detectors.

A fourth nonstandard technique of some OM4+ cabling suppliers attempts to use modal dispersion characteristics to offset chromatic dispersion. This technique is referred to as chromatic dispersion compensating fiber.

CHROMATIC DISPERSION COMPENSATING FIBER

Before we can delve into the details of this fourth technique, it is necessary to have some understanding of the transmitter characteristics that impact its effectiveness. Vertical cavity surface emitting lasers (VCSELs), the main type of light source used in transmitters for MMF applications, exhibit a spectral distribution profile such as that illustrated on the left of Figure 2.

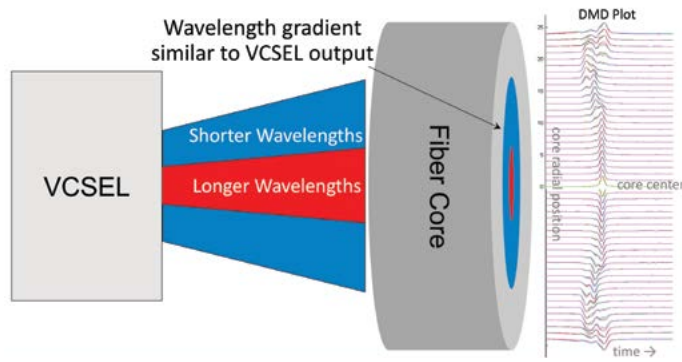

FIGURE 2 – Side view of VCSEL spatial-wavelength characteristic and wavelength gradient in fiber core when well aligned

The longer wavelengths (red) tend to have more power closer to the laser's central axis, and the shorter wavelengths (blue), tend to be more powerful on the VCSEL's outer circumference. If this characteristic is present and coupled to the fiber in such a way that it is also preserved within the fiber core, then this spectral distribution will tend to produce chromatic dispersion that is also spatially skewed rather than evenly distributed. If modal delays are held constant, the longer wavelengths in the center of the fiber's core will arrive earlier than the shorter wavelengths in the outer periphery of the core.

Supporters of OM4+ contend that complementary modal delay characteristics, as illustrated on the right of Figure 2, can offset this chromatic delay, reducing overall dispersion. Here the modes on the outer circumference of the fiber core arrive earlier than those near the fiber core's center, thus offsetting the chromatic dispersion tendencies. This theory of chromatic dispersion compensation, however, runs aground in practice.

Ensuring a net reduction of overall dispersion necessitates imposing a spacial-wavelength distribution requirement on the transmitter. In the absence of such a specification, the chromatic dispersion characteristics can, and often do, vary greatly from transceiver to transceiver and manufacturer to manufacturer. There are two main reasons why this variation exists. First, misalignment of the VCSEL to the fiber core will tend to mix the transmitter's wavelengths among fiber modes, muddling the spectral skew in the fiber. Figure 3 illustrates this mixing by showing longer wavelengths spreading into higher radii and the shorter wavelengths into lower radii, with an overall expansion of the mode power over a larger radius. Second, as illustrated in Figure 4, transceiver manufacturers are using diffractive lens systems that intentionally mix the VCSELs spectrum into the fiber in order to improve transmission characteristics. This renders the compensation technique ineffective. So, even if the theory of chromatic dispersion compensation is correct, assuring its benefits in the absence of a specification is impossible—rendering this claimed benefit of some OM4+ fibers highly suspect.

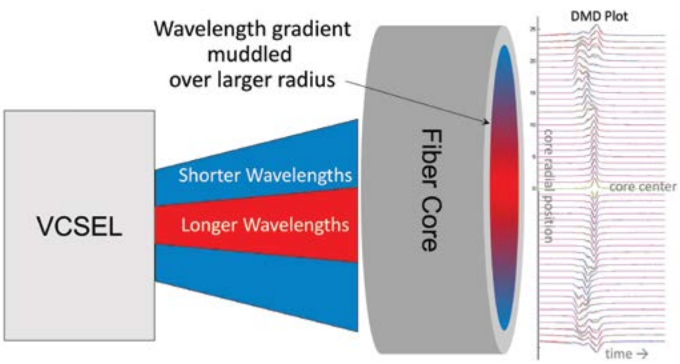

FIGURE 3 – Side view of VCSEL spacial-wavelength characteristic and wavelength gradient in fiber core when not well aligned

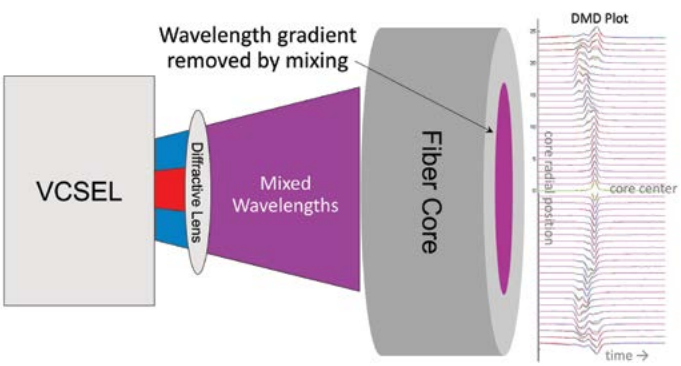

FIGURE 4 – Diffractive optic mixes wavelengths removing gradient in fiber

EFFECTIVE MODAL BANDWIDTH

Accurately assessing OM4+ versus OM5 also involves sorting through the various claims regarding EMB performance. These claims vary by OM4+ manufacturer and range from 5000 to 5640 MHz•km at 850 nm. Compared to the accepted 850 nm EMB of OM5—4700 MHz•km—this would appear to strengthen the case for OM4+.

However, a 2010 study on the relationship between EMB and application performance shows that raising EMB above approximately 4700 MHz•km yields small and diminishing improvement in application performance (see Figure 5). So, even if claims of higher EMB can be verified, there appears to be no real benefit in terms of application support.

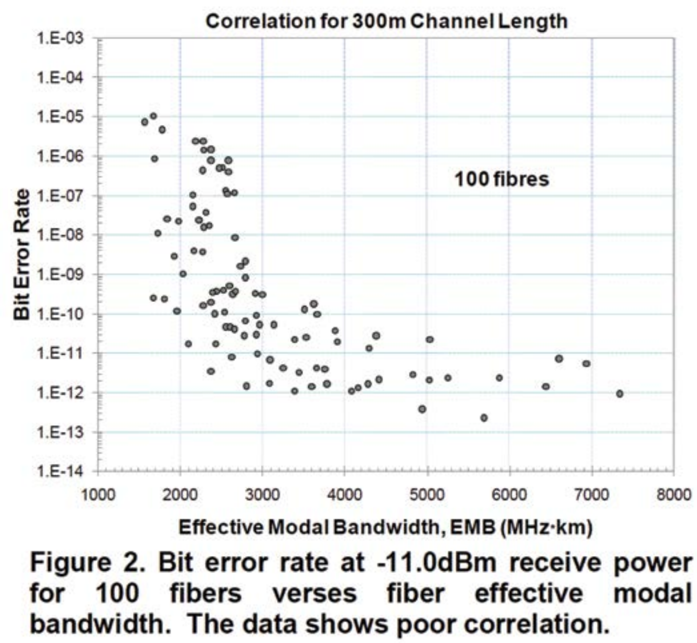

FIGURE 5 – Small and diminishing improvements in performance with EMB higher than that of OM4

Perhaps a more meaningful metric in comparing OM4+ and OM5 is the ability to support applications involving multiple wavelengths. Here, OM5—which was designed to support longer reach for multi-wavelength applications—has a decided and important advantage. As seen in Table 2, OM5 provides a minimum EMB of 2470 MHz•km for 953 nm, while some OM4+ fibers support just 1950 MHz•km for 953 nm. Other OM4+ manufacturers offer no information on the 953 nm bandwidth.

Instead, they emphasize increased 850 nm bandwidth, which—as previously demonstrated—offers little benefit for standard applications. As data center operators continue to migrate to higher-bandwidth multi-wavelength technologies like 40G-BiDi, 40G-SWDM4 and 100G-SWDM4, the ability to maintain high EMB for multiple wavelengths will grow more important. For example, the 100G-SWDM4 MSA supports distances up to 150 meters when operating over OM5—50 percent longer than OM4—but the MSA does not recognize OM4+.

TABLE 2: KEY BANDWIDTH METRICS OF SOME LASER-OPTIMIZED MMFs

FIBER TYPE	EMB @ 850 nm	EMB @ 953 nm
OM4	4700 (MHz-km)	Not Specified
OM5	4700 (MHz-km)	2470 (MHz-km)
OM4+	5000 (MHz-km)	1950 (MHz-km)

It should also be noted that some manufacturers have begun using a proprietary performance measurement known as "effective bandwidth" (EB), which combines the effects of modal and chromatic dispersion. It is important to remember that EB and EMB are not the same, nor are they directly comparable.

WHY STANDARDS COMPLIANCE MATTERS

As discussed, the interaction between transmitters and fiber plays a key role in the operation of high-speed optical fiber channels. Ensuring high transmission fidelity is the result of a cooperative relationship between transceiver and fiber manufacturers working toward a mutually beneficial MSA or standard and adhering to common and accepted specification methodologies. A good example is the synergy created between the early developers of OM5, including CommScope, and those driving the development of SWDM4 transceivers. Both technologies were developed concurrently, with each being able to build on the progress of the other. When OM5 was paired with 100G-SWDM4, the supportable channel length was increased by 50 percent compared to the reach over OM4.

Results such as this are the product of sustained efforts on the part of the MSA transceiver partners as well as the fiber standards bodies. The specification standards for OM5—and the application standards that reference them—have been in development since October 2014.

OM5 STANDARIZATION MILESTONES

Fiber Spec published by TIA TR-42, June 2016

- TIA 492AAAE

Added to ANSI/TIA-568.3-D, October 2016

- Defines wideband (a.k.a. OM5) cabling

OM5 added to ISO/IEC 11801-1

- References IEC 60793-2-10 ed. 6 fiber spec, 2017

For Ethernet & Fiber Channel

- Referenced in drafts 802.3bs and 802.3cd for 50G, 100G, 200G, 400G Ethernet
- Referenced in draft FC-P17 for 64G Fibre Channel

SWDM Alliance

- CommScope is charter member

ENGINEERING CHANNELS WITH OM5 WIDEBAND MMF AND ULL APPARATUS

While OM4+ performance claims regarding CD compensation remain generally suspect and the EB metric is proprietary, those promoted by OM5 manufacturers in support of multi-wavelength applications are not. Plots showing the differential mode delay (DMD) spanning the wavelengths used by BiDi and SWDM4 applications are shown in Figure 6. Using these DMD results, the EMB can be calculated for each wavelength. In fact, this measurement forms the basis for compliance to the specifications for fibers within OM5 cables. More than performance "claims," these specifications are fully vetted and measured using industry-accepted standard methods. As a result, data center operators and physical layer OEMs can be certain these OM5 cables will perform as stated.

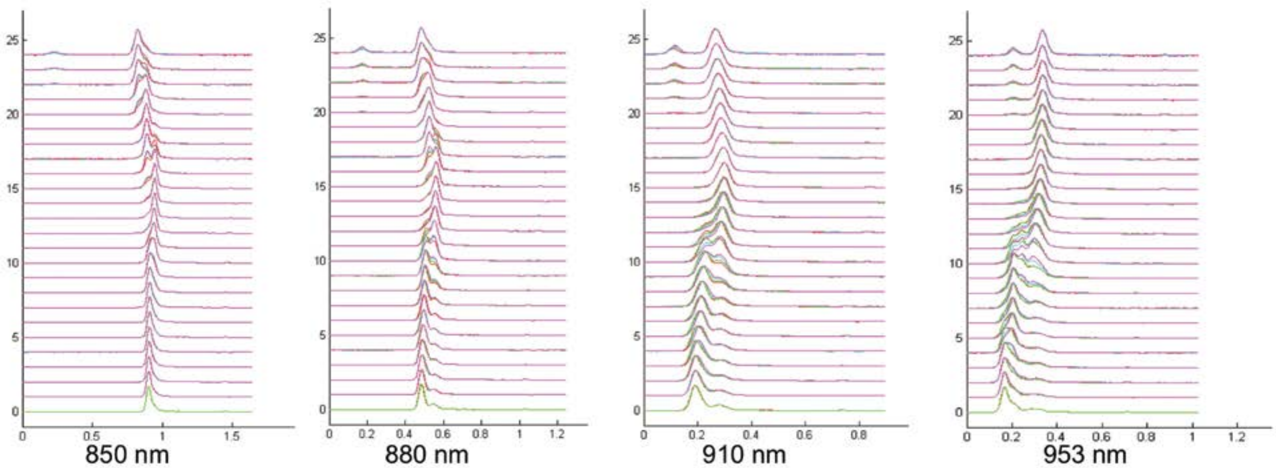

FIGURE 6 – DMD plots of OM5 fiber for wavelengths spanning both BiDi and SWDM4 applications.

For example, CommScope's OM5 application support guidelines for 40G-BiDi, which employs two wavelengths, using ultra low-loss (ULL) apparatus shows a significantly longer reach of 210 m maximum compared to OM4's 155 m maximum reach. See Table 3. Channel topologies for four-wavelength 100G-SWDM4 also benefit from OM5's wider bandwidth and ULL apparatus as shown in Table 4. Besides extending the reach by 50 percent when compared to OM4, the ULL connection performance maintains the 150-meter reach despite the presence of many connections.

TABLE 3: 40G-BiDi CHANNEL TOPOLOGY LIMITS WITH ULL APPARATUS

40 Gigabit Ethernet, Cisco "BiDi" (QSFP-40G-SR-BD)
Supportable Distance ft (m)

	LazrSPEED OM5 Wideband					
# LC CONNECTIONS* WITH:	1 MPO	2 MPOs	3 MPOs	4 MPOs	5 MPOs	6 MPOs
0	690 (210)	690 (210)	660 (200)	660 (200)	620 (190)	620 (190)
1	690 (210)	660 (200)	660 (200)	660 (200)	620 (190)	620 (190)
2	660 (200)	660 (200)	660 (200)	620 (190)	620 (190)	590 (180)
3	660 (200)	660 (200)	620 (190)	620 (190)	620 (190)	590 (180)
4	660 (200)	660 (200)	620 (190)	620 (190)	590 (180)	590 (180)
5	660 (200)	620 (190)	620 (190)	590 (180)	590 (180)	590 (180)
6	620 (190)	620 (190)	620 (190)	590 (180)	590 (180)	560 (170)

TABLE 4: 100G-SWDM4 CHANNEL TOPOLOGY LIMITS USING ULL APPARATUS						
100 Gigabit Ethernet, 850 nm SWDM (100G-SWDM4) Supportable Distance ft (m) LazrSPEED OM5 Wideband						
# LC CONNECTIONS* WITH:	1 MPO	2 MPOs	3 MPOs	4 MPOs	5 MPOs	6 MPOs
0	490 (150)	490 (150)	490 (150)	490 (150)	490 (150)	490 (150)
1	490 (150)	490 (150)	490 (150)	490 (150)	490 (150)	490 (150)
2	490 (150)	490 (150)	490 (150)	490 (150)	490 (150)	490 (150)
3	490 (150)	490 (150)	490 (150)	490 (150)	490 (150)	490 (150)
4	490 (150)	490 (150)	490 (150)	490 (150)	490 (150)	480 (145)
5	490 (150)	490 (150)	490 (150)	490 (150)	490 (150)	480 (145)
6	490 (150)	490 (150)	490 (150)	490 (150)	480 (145)	460 (140)

CONCLUSION

After comparing the capabilities, performance and application value of OM4+ and OM5, it is clear that proprietary OM4+ fiber cannot be considered equivalent to OM5. This should not be surprising, however, as they were developed for two very different purposes. OM5 was created to improve the reach of emerging multi-wavelength technologies like 40/100G SWDM4 and 40GBiDi, while OM4+ was developed to provide incremental improvements over the existing OM4 MMF.

As bandwidth demands continue to increase inside the data center—and the migration to multi-wavelength applications operating over longer links increases—it is important that data center operators understand the differences between OM4+ and OM5. More important, perhaps, is being able to accurately evaluate the merits of any standards-recognized technology versus a proprietary solution that claims to be as good or better.

The evolution of fiber in the data center will continue, and there will always be new solutions that begin as proprietary. Those that are eventually incorporated into the industry specifications are the ones that that provide the greatest assurance of application support improvements.

[1] R. Pimpinella et. al.; IWCS; 2010

CommScope (NASDAQ: COMM) helps design, build and manage wired and wireless networks around the world. As a communications infrastructure leader, we shape the always-on networks of tomorrow. For more than 40 years, our global team of greater than 20,000 employees, innovators and technologists has empowered customers in all regions of the world to anticipate what's next and push the boundaries of what's possible.

Discover more at commscope.com

COMMSCOPE®

commscope.com

Visit our website or contact your local CommScope representative for more information.

WP-112278-EN (11/17)