10 Gigabit Ethernet over Fiber Operation: More Range Than You Thought

Marty Anderson
Product Line Manager, Fiber Optic Cable Assemblies
Corning Cable Systems - EMEA

The Issue

In discussions today about fiber optic cabling solutions, there is a lot of talk about 10 Gigabit Ethernet: It's fast. It's better. It's aqua*. It has been said that 10 Gigabit Ethernet is clearly defined: maximum length is 300 meters and maximum attenuation is 2.6 dB between two active devices (or MDIs – media device interfaces). It has also been said that, according to the standard, if the system exceeds either of these values, it won't work. The reality is, the operating range is not as fixed as people believe. More operating range is actually available. In this article we try to clear up some of the myths about 10 Gigabit Ethernet operation.

Over the past years, there have been new developments in cabling related to 10 Gigabit Ethernet-over-fiber applications. There is also a protocol and physical layer standard defined by the Institute of Electrical and Electronic Engineers (IEEE) in the IEEE 802.3ae document. A new fiber standard category has been developed for laser-optimized multimode fiber (LOMMF): OM3. There is significant increase in the use of Vertical Cavity Surface Emitting Lasers (VCSELs), the higher speed, better focused and economical transmitters operating within the 850 nm multimode window. A new color code has been adopted to identify 10 Gig LOMMF cabling components: aqua (a shade between blue and green).

But with all of these developments, one still lacks the guidance to confidently know when a system will work under the broad range of real-world conditions.

The 10 Gigabit Ethernet Fiber Standard

Clause 52 of the 10 Gigabit Ethernet standard (IEEE 802.3ae) defines serial transmission. There are multiple fiber types and ranges defined. We will focus exclusively on the section applicable to most commercially available fiber optic solutions for local area networks (LANs): LOMMF with a 50 µm core, 850 nm wavelength, and maximum operating distance of 300 m. These details are captured in the definition of the 10GBASE-SR physical medium dependent (PMD) sub-layer in the standard.

Name	Description	Comment
10GBASE-SR	850 nm Serial LAN PHY	Device supports shortwave 850 nm operation LAN PHY
10GBASE-LR	1310 nm Serial LAN PHY	Device supports longwave 1310 nm operation LAN PHY
10GBASE-ER	1550 nm Serial LAN PHY	Device supports extra longwave 1550 nm operation LAN PHY
10GBASE-SW	850 nm Serial WAN PHY	Device supports shortwave 850 nm operation WAN PHY
10GBASE-LW	1310 nm Serial WAN PHY	Device supports longwave 1310 nm operation WAN PHY
10GBASE-EW	1550 nm Serial WAN PHY	Device supports extra longwave 1550 nm operation WAN PHY

Table 1: Names of 10 Gigabit Ethernet Physical Medium Dependent (PMD) sub-layers supporting the listed (PHY) physical layer device.

** Aqua is the blue-green or turquoise color which has been identified to represent OM3 laser optimized 50µm multimode fiber used in 10Gigabit fiber optic cabling systems: connector and adapter components and cable jackets should be marked in aqua for OM3.*

The IEEE 802.3ae standard defines a channel for 10GBASE-S as shown in Figure 1 below. Two media device interfaces (MDIs) are connected via 300 meters of fiber with two connection points.. The connector pairs contribute a total of 1.5 dB attenuation (assuming a maximum 0.75 dB/connector pair) and the fiber approximately 1.1 dB (assuming 3.5 dB/km @ 850 nm). Remember fiber connectors only contribute a loss to the system when mated to another connector.

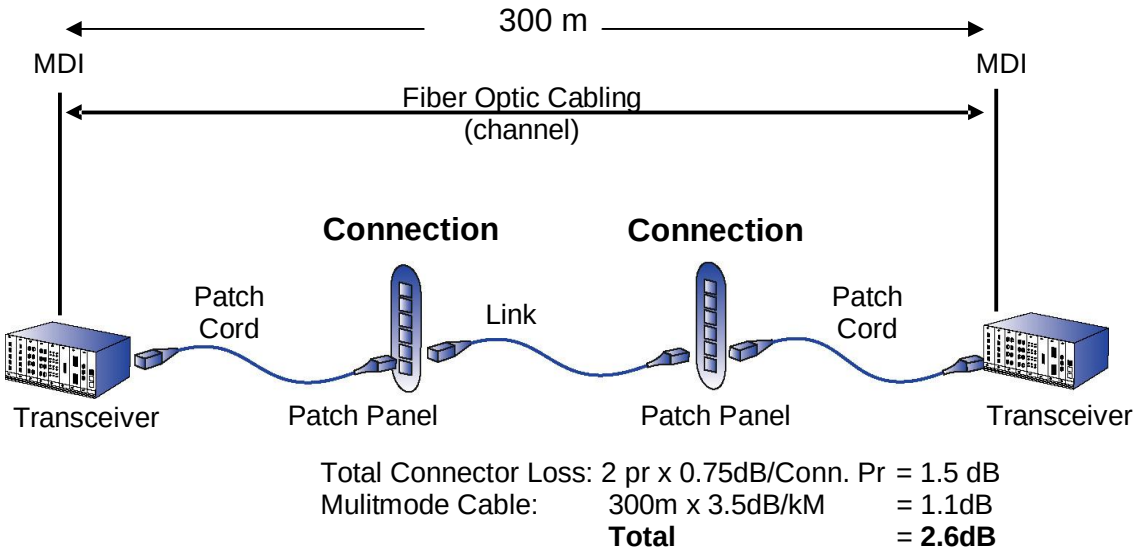


Figure 1: Channel Defined by IEEE 802.3ae, 10GBASE-SR

Following the channel description in the standard, there is a table (Table 52-10), which states clearly the maximum values for a 10 Gigabit channel over LOMMF 50 µm fiber with an 850 nm source: 300 m and 2.6 dB. So, it is not possible for a 10 Gig system to operate when channel loss is greater than 2.6 dB, right? Wrong.

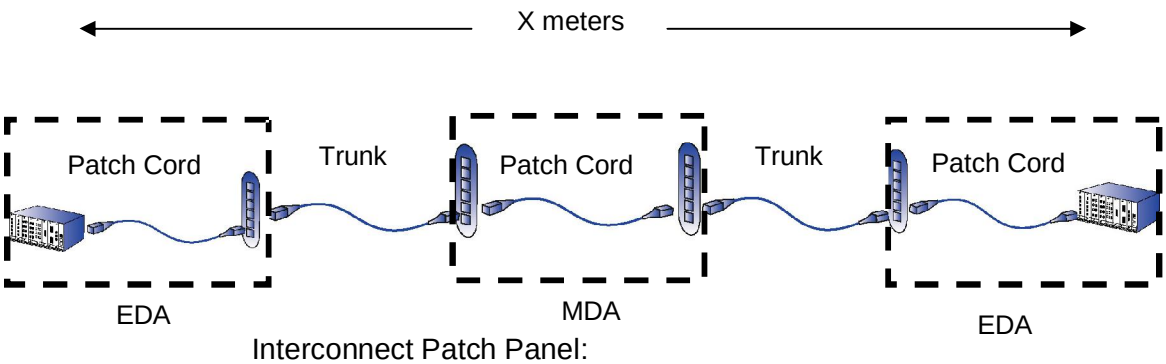
Parameter	***62.5 µm MMF***		***50 µm MMF***			***Unit***
Modal Bandwidth Measured at 850 nm	160	*200*	*400*	*500*	*2000*	*MHz-km*
Power Budget	*7.3*	*7.3*	*7.3*	*7.3*	*7.3*	*dB*
Operating Distance	*26*	*33*	*66*	*82*	*300*	*m*
Channel Insertion Loss	*1.6*	*1.6*	*1.7*	*1.8*	*2.6*	*dB*
Allocation for penalties	*4.7*	*4.8*	*5.1*	*5.0*	*4.7*	*dB*
Additional Insertion Loss Allowed	*1.0*	*0.8*	*0.5*	*0.5*	*0.0*	*dB*

Table 2: IEEE802.3ae Table 52-10 10G BASE-S power link budgets
**The 2.6dB value is also printed in TableE.3 of the EN50173 standard.*

The maximum loss of 2.6 dB is actually calculated as the difference between an allowable system *power budget* of 7.3 dB and an *allocation for penalties* value of 4.7 dB (7.3 – 4.7 = 2.6). The *allocation for penalties* considers operating conditions associated with the electronics (MDIs) and inter-symbol interference such as: transmitter stability, center wavelength, coupling losses (into fiber from a transmitter), chirp, power penalties gained with reduced channel length, connector loss, fiber loss, bandwidth, etc. We will address how these allocations are determined later.

A Source of Confusion: To Which Standard are You Referring?
There are many standards directing and guiding system designers. The most commonly referred to for data centers are the structured cabling standards for cabling systems: EN50173 Chapter 5 (Europe) and TIA/EIA 942 (NAFTA). When one reads these standards and compares what is written in IEEE 802.3ae, there may be some confusion.

Because the IEEE 802.3ae channel is not representative of a complete end-to-end signal in a structured cabling system with more than two connector pairs, it can be confusing to understand the difference between what is acceptable for 10 Gb/s transmission and which system designs conform to the standard. In a structured cabling system for data centers as prescribed in TIA/EIA 942 or EN50173 Chapter 5, there are typically at least four connector pairs as shown in Figure 2 below. If we assume the standard maximum loss per connector pair of 0.75 dB, then with four connectors we have already exceeded the maximum loss stated in the IEEE 802.3ae. Is it possible, then, to have four connector pairs in your 10 Gig system? Yes, because the "maximum" loss of 2.6 dB applies only when the maximum length of 300 meters is achieved. If the system length is reduced less than 300 meters, then higher attenuation can be tolerated. In the *allocation of power penalties in Table 2*, power penalties are gained as a result of reducing channel length. The question remains, how much shorter must the system become when using four connector pairs?



Interconnect Patch Panel:
Total Connector Loss: 4 x 0.75/Conn. Pr. = 3.0 dB
Mulitmode Cable = X m x 3.5dB/kM = ? dB
Total Loss: **= ? dB**

MDA - Main Distribution Area
EDA - Equipment Distribution Area

Figure 2: End-to-End Path in Structured Cabling System per EN50173 Chapter 5 and TIA/EIA942

When a new transmission protocol is introduced in the market, the standards bodies create guidelines and recommendations for systems implementing these protocols. Lay-people are often intimidated when they first look into the standards, seeing formulas, complex diagrams, foreign symbols and a writing style that one assumes only a lawyer or physicist could interpret. Instead of needing to make calculations to determine if our system will operate (as suggested above in Figure 2), most of us prefer to see a simple table with a column header "maximum distance" and another column showing the "maximum attenuation". From such a simple table, we can easily determine what to do in each case we face when planning a structured cabling solution. Next, we'll look at how such a table can be constructed for simpler determination of the maximum system length and attenuation which will still allow 10 Gig operation.

The 10 Gigabit Working Model and Determination of Other Operating Ranges
A model was created based on the 10 Gig IEEE 802.3ae standard in order to help generate a set of operating ranges with many different variables to determine the *allocation for penalties*, *channel insertion loss*, and *additional insertion allowed* values listed in Table 2 above. This model was created by the IEEE 802.3ae committee. Their model allows one to consider many variables and their interactions simultaneously to then determine maximum loss and maximum length for a given set of variables or conditions. From that model we can create a set of maximum losses and lengths based on some generally accepted common parameters of the equipment and passive components. So, by adjusting parameters such as link length, fiber bandwidth and connector losses, we can in fact reach a simple distance and loss table as shown below in Table 3 below.

				Distance(m)/ Channel Loss (dB)					
				Number of Connector Pairs					
Cable Description	**Max. Loss per Conn. Pair (dB)**	**Cable fiber atten. (dB/Km)**	**Data Rate (10Gb/s)**	**2**	**3**	**4**	**5**	**6**	**7**
Laser-Optimized 50/125 um Pretium™ 300 Solution	0.75	3.0	10	300 / 2.77	280 / 3.28	250 / 3.92	220 / 4.45	180 / 5.02	120 / 5.62

Table 3: 10GBASE-S Distance Capability and Channel Insertion Loss in a Structured Cabling System Using Corning Cable Systems Products

Beyond the traditional cabling systems with connectors directly terminated on the ends of the trunk cables (shown in Figure 2), today we also see Plug and Play™ Modular Systems which utilize a trunk with high-fiber-density MTP® Connectors (12 fibers in one connector), which are then connected to modules in patch panels. The module accepts an MTP Connector on the rear side and presents a standard LC, SC or MT-RJ interface to the user on the front side of the panel for easy jumper connection to active equipment or other ports for cross connection (Figure 3).

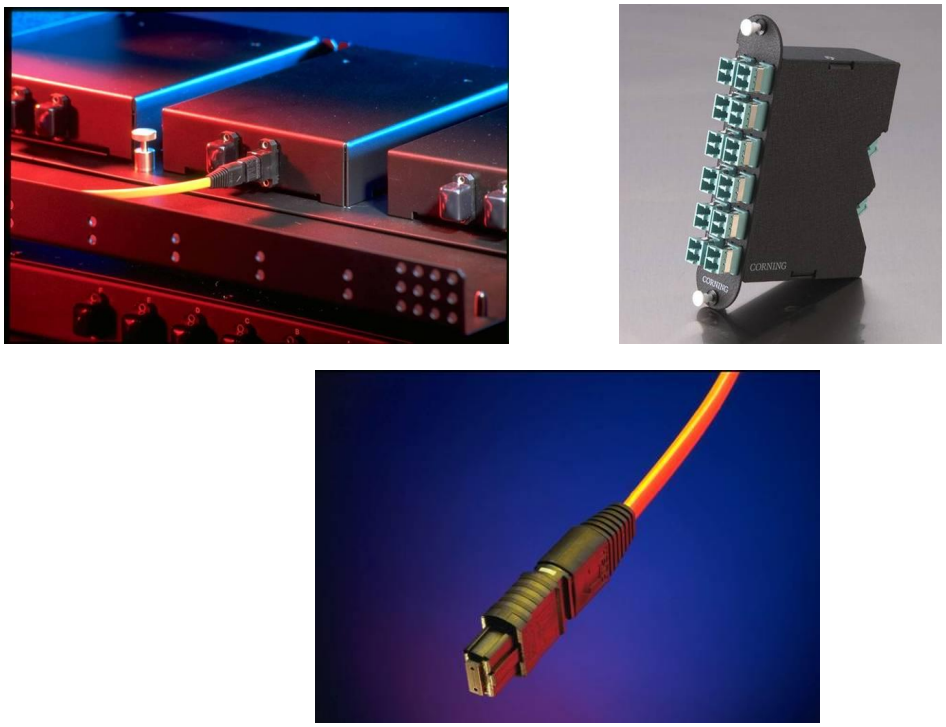


Figure 3: Corning Cable Systems Plug and Play Module System (clockwise from upper left) Rear view of module with MTP connector, Front view of module with LC Duplex adapters, close-up view of MTP 12-fiber connector at end of trunk.

These solutions allow end-users to install a structured cabling system in as little as one-fifth the time required compared to install a traditional field-terminated system on the job site, whether the traditional system employs epoxy-and-polish connectors or spliced pigtail solutions. Systems implementing Plug and Play™ Systems can save data center operators millions of Euros for every day the system is running ahead of schedule. The one factor planners must consider with Plug and Play Systems is the additional loss of the extra connection at the MTP® Connector trunk-to-module point. Typically, a cumulative loss of 1.3 dB is assumed for the MTP Connector on the rear of the module and the connector on the front of the module. In order to show that 10 Gb/s systems function equally well on Plug and Play Systems, we have re-run the model and presented the results in the table below. The combination of values listed in both the connector pair table (Table 3) and the module table (Table 4) have been assimilated and are shown in the graph below (Figure 4).

				Distance(m)/ Channel Loss (dB)					
				Number of Connector Modules					
Cable Description	**Max. Loss per Module (dB)**	**Cable fiber atten. (dB/Km)**	**Data Rate (10Gb/s)**	**2**	**3**	**4**	**5**	**6**	**7**
Laser-Optimized 50/125 um Pretium™ 300 Solution	1.3	3.0	10	270 / 3.50	210 / 4.61	120 / 5.62	N/A	N/A	N/A

Table 4: 10GBASE-S Distance Capability and Channel Insertion Loss for Modules in Structured Cabling System using Corning Cable Systems' Plug and Play Products

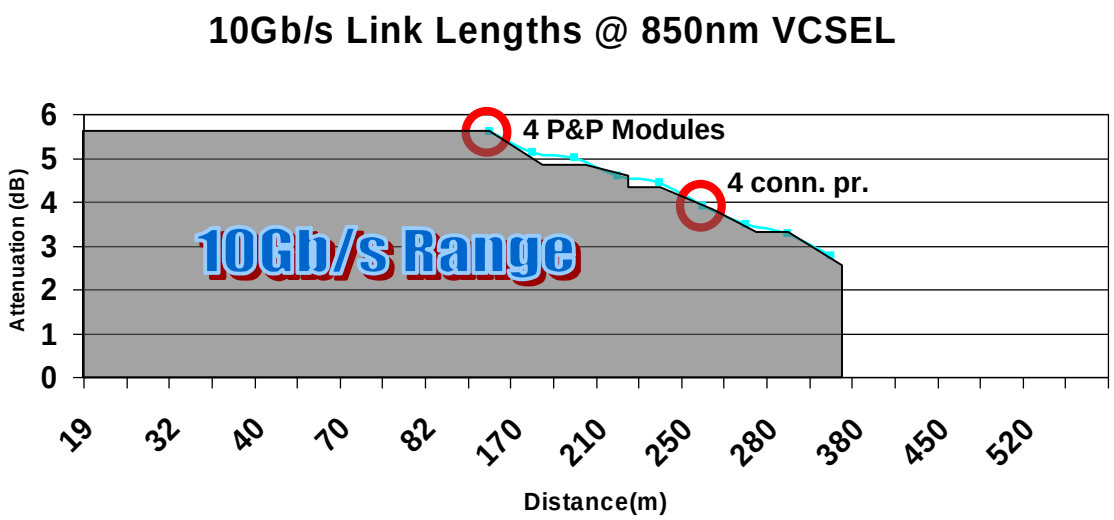


Figure 4: Operating Points for 10 Gb/s Systems. Connector Loss and Module Loss
Note: Horizontal axis is not linear.

A Wider Range for Attenuation in 10 Gig Ethernet Than You Thought

Although it is written in the IEEE 802.3ae specification that the maximum allowable loss for a 10 Gb/s system is 2.6 dB (at 300 meters), it must be understood how this maximum loss is calculated and its relationship to system length. When the 10 Gb/s model is analyzed, then one sees that higher system losses are acceptable in a 10 Gb/s system and that the system will operate successfully, though over a shorter distance.

The key messages for 10 Gig over fiber operation are:

- The IEEE 802.3ae document assumes conservative conditions to determine maximum loss and maximum distance values.
- When the 10 Gig model is configured assuming actual operating conditions for the passive components (influenced by fiber and connector performance), we can realize other operating points that still allow 10 Gig operation at higher attenuation values.
- A 10GBASE-R defined channel with higher loss can still operate at 10 Gb/s, though not at a distance of 300 meters over LOMMF 50 µm fiber.

References:

Doug Coleman, Manager, Technology and Standards, Private Networks, Corning Cable Systems

Review of the 10 Gigabit Ethernet Link Model, White Paper, Authors: D. Cunningham, P.Dawe, Agilent Technologies, ONIDS 2002

Part 3: Carrier Sense and Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications – Amendment: Media Access Control (MAC) Parameters, Physical Layers, and Management Parameters for 10Gb/s Operation, IEEE Standard 802.3ae, IEEE Computer Society, August 30, 2002.

ANSI/TIA/EIA-568-B.3, Optical Fiber Cabling Components Standard

ANSI/TIA/EIA-942

EN50173, Chapter 5: Information technology - Generic cabling systems Part 5: Data centres, CENELEC, 2002

Biography of Author Marty Anderson:

Marty Anderson is currently the Product Line Management for Cable Assembly (Fiber Optic) products for Corning Cable Systems in EMEA. Anderson has been a Corning Cable Systems employee since 1992. His previous positions have been Product Line Manager Fiber Optic Connectors EMEA, Product Line Manager Fusion Splicers in NAFTA and Field Engineer. Prior to his employment at Corning Cable Systems, Anderson worked for IBM and AT&T in various roles. Anderson is certifies Electrical Engineer and has received his BSEE from North Carolina State University in the U.S.

Corning Cable Systems GmbH & Co. KG · Rotherstrasse 21 · 10245 Berlin, Germany
TEL: 00800-2676-4641 (00800-CORNING1) · FAX: +49-30-5303-2335 · http://www.corning.com/cablesystems