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MULTIMODE FIBER EFFECTS ON CONNECTOR INSERTION LOSS

OFS FITEL, LLC

OFS, 2000 Northeast Expressway, Norcross, GA 30071 USA

Executive Summary

Today's high-speed multimode systems require high performance optical fiber links. As network speeds have increased, link loss budgets have become tighter, driving a need for lower connector insertion loss and cable attenuation. While standards set a benchmark, they only provide a minimum performance level which may not be sufficient to support the multi-connection links found in networks today. To consistently achieve low insertion loss, a number of factors need to be controlled, including connector ferrule geometry, termination practices, and fiber characteristics. This paper will focus on the contribution fiber attributes make in achieving low connector insertion loss.

Standards

The Telecommunications Industry Association (TIA) in North America and the worldwide International Electrotechnical Commission (IEC) organizations are responsible for publishing standards defining both fiber and connector requirements. These standards set accepted minimum requirements within the industry. ANSI/TIA-492AAAF and IEC-60793-2-10 define multimode fiber requirements while ANSI/TIA-568.3-D and ISO/IEC 11801-1 define cabling requirements. IEC 61753-1 defines performance standards for optical interconnecting devices and define two different attenuation grades for random mated multimode fibers:

Attenuation Grade	Attenuation @ 850 nm IEC 61300-3-34 for single-fiber connector and IEC 61300-3-45 for multi-fiber connector	
Grade Bm	≤ 0.3 dB mean	≤ 0.6 dB max. for ≥ 97% of the connections
Grade Cm	≤ 0.5 dB mean	≤ 1.0 dB max. for ≥ 97% of the connections

TABLE 1

Application standards are increasingly driven by IEEE 802.3 Ethernet due to its acceptance not just in the enterprise market, but also in service provider and hyperscale networks. Other organizations, including Fiber Channel and OIF also publish application standards, but are often influenced by activity in IEEE. As network speeds have increased, the loss budgets for the optical link have decreased. Looking at the table below, link power budgets have fallen from over 3.5 dB for Gigabit Ethernet, to 1.7 dB for 400 Gb/s SR4.2 Ethernet, and 1.8 dB for Fiber Channel applications.

						Link Power Budget (dB)		
		Gb/s/lane	Fiber Pairs	ƛ	Wave-length	OM3	OM4	OM5
1000BASE-SX	1 Gb/s	1	1	1	850 nm	3.56	3.56	
10GBASE-SR	10 Gb/s	10	1	1	850 nm	2.60	2.90	
40GBASE-SR4	40 Gb/s	10	4	1	850 nm	1.9	1.5	
40Gb/s BiDi	40 Gb/s	20	1	2	850/900 nm	1.5*	1.5*	
40Gb/s SWDM4	40 Gb/s	10	1	4	850-940 nm	2.0	1.9	1.9
100GBASE-SR4	100 Gb/s	25	4	1	850 nm	1.8	1.9	
100 Gb/s BiDi	100 Gb/s	50	1	2	850/910 nm	1.5*	1.5*	1.5*
100 Gb/s SWDM4	100 Gb/s	25	1	4	850-940 nm	2.0	1.9	1.9
400GBASE-SR8	400 Gb/s	25	8	1	850 nm	1.8	1.9	1.9
400GBASE-SR4.2	400 Gb/s	25	4	2	850/910 nm	1.7	1.8	2.0
16GFC	16 Gb/s	16	1	1	850 nm	1.86	1.95	
32GFC	32 Gb/s	32	1	1	850 nm	1.87	1.86	
64GFC	64 Gb/s	64	1	1	850 nm	1.86	1.86	1.86

TABLE 2

* 1.5 dB allocated for connection and splice loss.

Modules and Cross Connects add to the number of connections

This decrease in loss budgets has driven an increased focus on connection loss. In many links, four or more connections are required. If four grade Cm connections are in a channel, link attenuation would be 2dB assuming average insertion loss, exceeding the loss budget for Ethernet applications that are 40Gb/s or higher, and Fiber Channel applications 16Gb/s and higher. Assuming higher grade Cm connections, links containing 6 connections would exceed link budgets when fiber cable contributions are included.

In applications using a single pair of fibers, breakout modules are frequently used to convert from 12-fiber based MPO connectorized cables to duplex LC, CS or SN connectors. See Figure 1. If a module is used at either end of a preterminated cable, a minimum of 4 connections is built into the link.

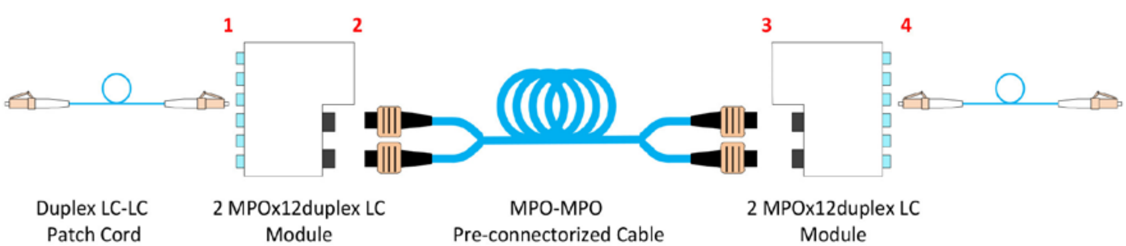


FIGURE 1: Four connection link with breakout modules

If a cross connect is used to provide flexibility at either end of the cable, more connections are added to the link. If multiple trunk cables are used in a link, additional connections are required. In figure 2, a two-trunk link is shown, with a total of six connections.

In an ideal fiber connection, two identical fiber cores will be centered inside the connector ferrule and perfectly align, and all light transmitted from one core will be captured by the second. It's comparable to mating two water pipes – if two pipes are the same size and butted up to each other, water will flow from one pipe to the next with no water lost. However, if a 4" pipe is butted to a 3" pipe, water will be lost.

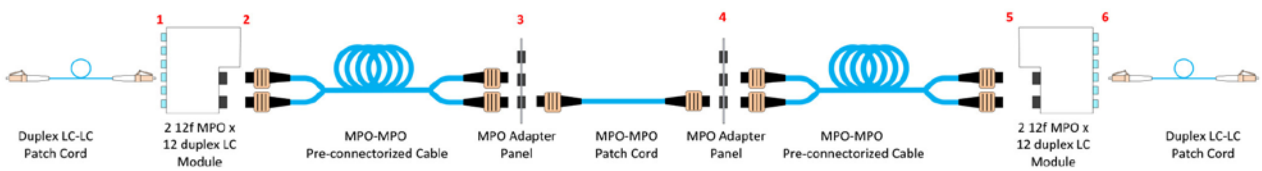


FIGURE 2: Cross Connect with two-trunk link and breakout modules

In order to support link flexibility, it can be seen that low connector loss is critical. This puts pressure on suppliers to support tighter average and maximum connector losses in their products. Low insertion loss is dependent on several factors, including:

1. Optical fiber properties
2. Connector/ferrule properties
3. Polishing process

Poor control of any of these properties can result in a high loss connection. While all three elements must be optimized to minimize insertion loss, this paper focuses primarily on the geometry and optical properties of the fiber.

Fiber effects on connector insertion loss

Multimode fiber standards define minimum geometry and optical requirements for use in standards based systems. These requirements are documented in ANSI/TIA-492AAAF and IEC 60793-2-10. Key parameters that affect connector insertion loss are shown below:

Parameter	IEC/TIA Requirements
Core Diameter	50 ± 2.5 μm
Core Non-circularity	≤ 6%
Clad Diameter	125 ± 1 μm
Clad non-circularity	≤ 1%
Core/clad concentricity	≤ 2.0 μm
Numerical Aperture (NA)	0.200 ± 0.015

TABLE 3

If there is core misalignment at a connection, light is lost. This misalignment could be caused by fiber geometry variations including clad diameter or core-clad concentricity. Ferrule geometry also affects core alignment. In an ideal connector, the fiber fits tightly in the connector ferrule bore, with a minimal gap between the fiber and the ferrule (Figure 3), resulting in a fiber core that is centered inside the ferrule.

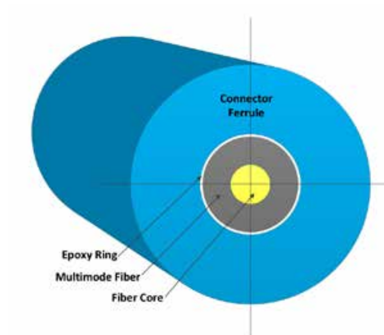


FIGURE 3

However, this gap between fiber and ferrule will be larger if the fiber diameter is not close to the ferrule bore diameter. This could be caused by a fiber that has a smaller clad diameter or by a ferrule that has a larger bore (Figure 4b). Either condition will lead to the fiber core not being centered in the connector ferrule, and core misalignment. Similarly, a core that is not centered inside the fiber (core-clad concentricity) would lead to misalignment (Figure 4c). Core non-circularity can also increase insertion loss when mated fiber cores don't overlap completely (Figure 4d).

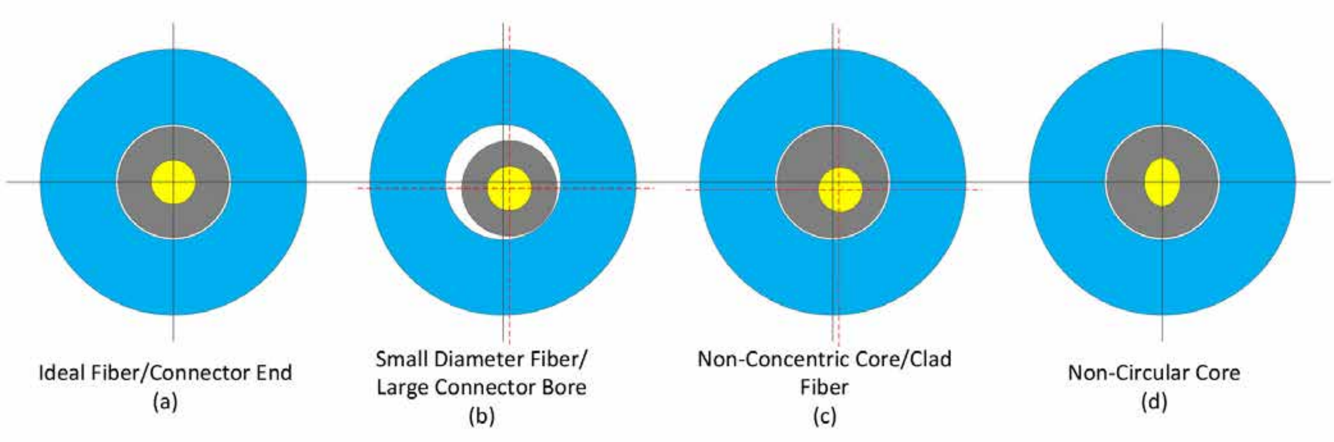


FIGURE 4

If an ideal fiber is overlaid onto each of these ends (Figure 5), it is apparent the cores will not be aligned optimally, contributing to higher connection loss.

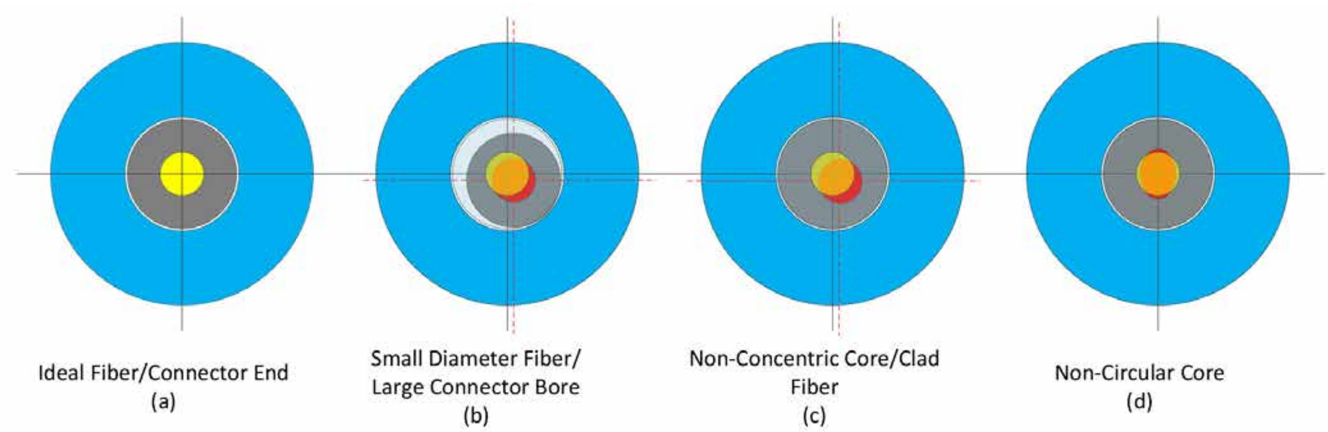


FIGURE 5

Fiber optical characteristics also can affect insertion loss. One of the key requirements is Numerical Aperture, or NA. NA defines the light acceptance cone of the fiber, and the range of angles that the light will be transmitted through the fiber core (Figure 6). Light at an angle outside the NA will be lost in the fiber cladding and not transmitted (red dotted line Figure 6).

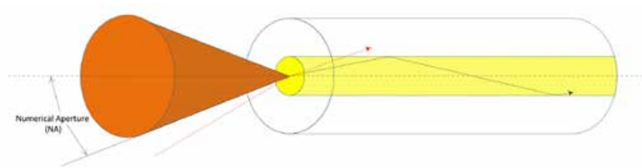
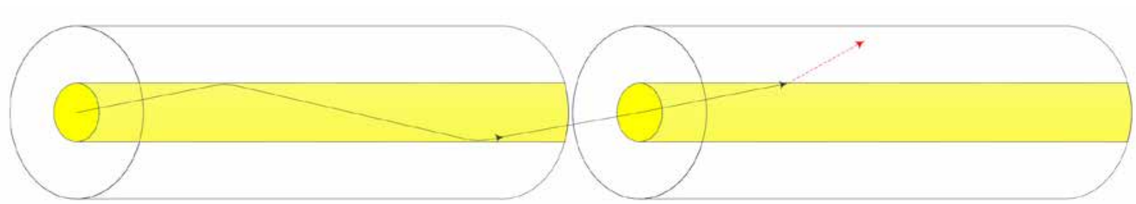


FIGURE 6

If two fibers with different NA value are connected, some light transmitted from the higher NA fiber will be lost in the lower NA fiber (Figure 7), contributing to a small amount of insertion loss. To help minimize insertion loss (minimize the amount of light lost outside the NA acceptance cone), a tighter tolerance on the NA acceptance cone is desirable.

All these fiber characteristics can affect connector insertion loss. By minimizing the fiber-to-fiber variation and tightening the specification limits, maximum and average insertion loss can be decreased.

In March 2021, OFS tightened LaserWave OM3, OM4, and OM5 multimode fiber specification limits for a number of characteristics. Table 4 provides a comparison between LaserWave fiber, IEC/TIA standards, and a competitor.



Higher NA Fiber **Lower NA Fiber**

FIGURE 7

Attribute	IEC 60793-2-10 TIA 492 AAAF (OM2/3/4/5)	OFS LaserWave Optical Fiber	Competitor
Attenuation	2.5 dB/km	2.2 dB/km	2.3 dB/km
Core Diameter	50 ± 2.5 mm	50 ± 2.5 mm	50 ± 2.5 mm
Numerical Aperture (NA)	0.200 ± 0.015	0.200 ± 0.010	0.200 ± 0.015
Clad Diameter	125 ± 1 μm	125.0 ± 0.7 μm	125 ± 1.0 μm
Core/Clad Concentricity	≤ 2 μm	≤ 0.7 μm	≤ 1.5 μm
Clad Non-circularity	≤ 1%	≤ 0.7%	≤ 1%
Core Non-Circularity	≤ 6%	≤ 2.5%	≤ 5%

TABLE 4

Through continuous engineering development and process improvements, OFS is able to offer the tightest multimode fiber specifications in the industry.

Modeling

By using a distribution of fiber and connector ferrule properties, Monte Carlo analysis can be used to forecast a distribution of connector insertion losses. Fiber and ferrule specifications provide the limits of the distributions that are used. By tightening the specifications around the nominal value, average insertion loss is decreased.

Modeling Results

Single fiber connector insertion loss results were generated with the Monte Carlo model, using each of the three specification sets listed in Table 4. Results of the modeling are shown in the following figure.

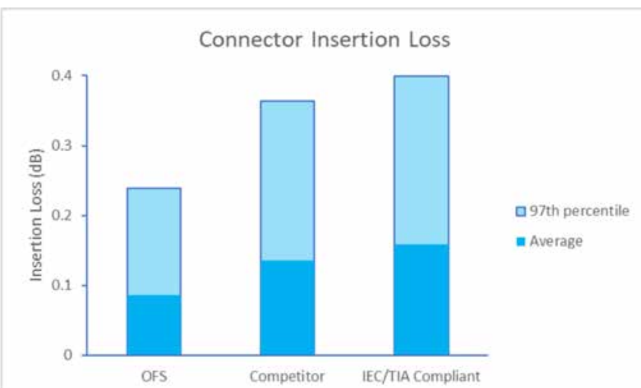


FIGURE 8

Figure 8 shows the effect of tightened fiber specifications on insertion loss values. By improving the specifications over industry standard requirements, average and 97th percentile insertion loss is over 40% less than standards compliant requirements, and 1/3 better than the competition. Even larger gains could be made by using ferrules with tighter tolerance bore ID, which would be feasible because of the fiber's tighter clad diameter specification.

Benefits

Lower average and 97th percentile loss provides benefits to both the cable assembly manufacturer and to the end user. For an assembly supplier, tighter specifications on clad diameter mean that it is easier to meet internal insertion loss requirements. It also means that fiber fit problems are a much smaller issue, as "fat fiber" occurrences are weeded out by the more demanding specifications.

For end users, more connections can be used in a link. Using a cross connect instead of an interconnect provides additional flexibility and ease of administration. Lower insertion losses also mean more performance headroom, which could provide safety margin against potential installation-related issues like excessive bends or slight over-contamination of a connector. By no means should connector cleanliness and proper fiber routing be relaxed, but lower insertion loss could help in marginal situations.

Conclusion

Today's high-speed systems demand high performance fiber. Tighter fiber specifications enable lower connector insertion loss, and even better performance can be achieved with tighter ferrule specifications.