

IS THERE VALUE IN BEND-INSENSITIVE MULTIMODE FIBER? AN EXAMINATION

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Bend-insensitive multimode fiber (BI-MMF) has been a frequent topic of discussion in the enterprise structured cabling industry. Several manufacturers have introduced fibers designed for tight bending applications, and one has converted all of their 50 μm multimode production to BI-MMF.

However, debates are ongoing in standards forums and technical symposia about the benefits and shortcomings of these fibers. Do they bring value to data center or enterprise applications? Are they needed? Have the fibers themselves been thoroughly investigated? Are BI-MMFs able to support high speed 10, 40, and 100 Gb/s applications at the same link distances as standard OM3 and OM4 fibers? This paper seeks to address these questions.

What's Different about Bend-Insensitive Fiber?

What makes a multimode fiber “bend-insensitive”? BI-MMF is not simply standard multimode fiber with lower bending loss. It is a new fiber design that alters the light guiding region, or “waveguide,” to improve bending loss (macrobend) performance. This is done by placing a trench around the core of the fiber, changing the properties of the light being guided (see Figure 1).

Changing the waveguide of the optical fiber is a complex process that impacts many other fiber properties, which in turn must be optimized. In fact, the changes made to improve bending loss often *degrade* other properties - including bandwidth and mating (connector) loss - that impact system

performance. The key question is, “Does the deployment of bend-insensitive multimode fiber improve the performance of an installed multimode fiber link?”

OFS and other manufacturers have examined the changes made to improve bend performance, and the resulting trade-offs. Studies have shown that bend-insensitivity can come at a high cost in both bandwidth and connection loss. To make matters worse, current standards requirements, especially those for laser-optimized bandwidth, do not account for the changes made to the BI-MMF waveguide. This can lead to systems performance that is poorer than what would be expected using current methods to estimate the laser bandwidth of the fiber.

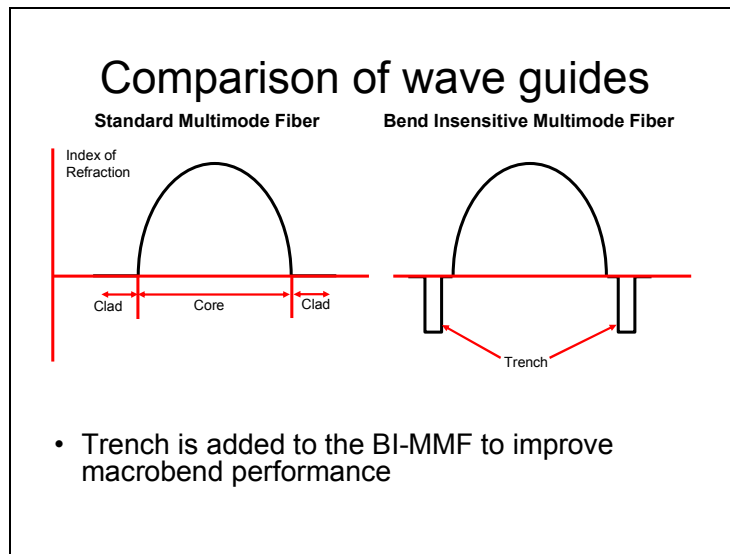


Figure 1

Sharp bends and kinks in a 1.6 mm or 2.0 mm jumper can have a negative effect on the mechanical reliability of the link. Studies have shown that sharp kinks in a jumper (such as would be caused when a jumper is closed in a cabinet door) can lead to fiber breaks. Encouraging installation practices that result in tight bends and kinks by using BI-MMF in the data center is both mechanically dangerous and unnecessary. Modern cable management systems and easy, common installation practices enable high density with reliability.

Today's BI-MMF can actually reduce overall system performance in enterprise and data center applications. Therefore, high performing and *already standardized* OM3 and OM4 fibers are better choices for high speed enterprise networks and data centers.

Taking a Closer Look

Since BI-MMF has not yet been standardized by the industry, it can be difficult to precisely define it. However, a rough definition of BI-MMF will be helpful before we discuss the trade-offs required in manufacturing this fiber. It has been suggested that this new type of fiber should have the following macrobend attributes:

≤ 0.1 dB at 850 nm for 2 turns around a 15 mm radius mandrel

≤ 0.2 dB at 850 nm for 2 turns around a 7.5 mm radius mandrel

BI-MMF was developed to simplify cable management. The objective of the new design was to reduce bending loss while maintaining all of the specifications that are currently listed for OM2, OM3 and OM4 multimode fiber. However, existing fiber and systems standards were all developed for a multimode fiber having a traditional waveguide. BI-MMF, with its added trench, has a *different* waveguide. As a result, many of the current measurements and standards do not accurately describe or predict the performance of BI-MMF. It is important to note that, unlike single-mode fiber, improved macrobend performance in multimode fiber does not lead to improved microbend performance. Switching to a BI-MMF will not improve microbending performance in demanding cable designs.

Evolution of the Ethernet standard (and other data networking standards) has led to increased data rates and lower channel insertion loss for short reach links. Channel insertion loss includes many properties, including cable attenuation, connector loss, and macrobend loss. BI-MMFs have higher mating loss when connected to standard multimode fiber (see Table 1). Simply lowering macrobend loss provides little benefit if other link loss contributors increase. If the goal is to minimize link loss, it is not logical to trade a pre-determined higher mating loss (*and link loss*) to protect against a

possible sharp bend that can be prevented by proper cable management, and could also introduce a mechanical failure point with a sharp kink under tension.

Fiber A	Fiber B	Median (dB)	Std.Dev. (dB)	$\mu + 3\sigma$ (dB)
Stand. OM3	Stand. OM3	0.22	0.06	0.40
BI-MMF Design Y	Stand. OM3	0.29	0.09	0.56
BI-MMF Design X	Stand. OM3	0.31	0.11	0.64

Table 1

Changing the Way Light Travels

Because of the trench, light is guided differently in a BI-MMF than in standard fiber. It must do this in order to decrease the amount of light lost in a macrobend. To see this difference, it is important to understand that modes propagating in multimode optical fibers can be classified as:

- Guided modes – modes that have an effective index greater than the cladding index
- Leaky modes – modes that have an effective index that is less than the cladding index (these are often referred to as “cladding modes”).

As light travels closer to the core/cladding interface, modes are less tightly bound in the core and can more easily be stripped away by a macrobend in a standard fiber. These higher order guided modes can be classified as “weakly guided modes.” Adding a trench around the core of the optical fiber guides these higher order modes more effectively, creating a multimode fiber with improved macrobend performance. The trench can also lead to an unfortunate side effect: leaky modes, which do not propagate in a standard fiber, can propagate several hundred meters in a BI-MMF and must be accounted for in connection loss and bandwidth calculations (see Figure 2). The difficulty in

measuring connector loss of BI-MMF is largely due to the challenge of properly accounting for both leaky modes and the light that is now strongly bound in the higher order modes.

The addition of more strongly bound high order modes and leaky modes can have dramatic system performance implications. Neglecting these modes in a BI-MMF may lead to overly optimistic system performance expectations. These modes were disregarded in the development of laser-optimized fiber standards because the light was so poorly guided. With the addition of the trench, these modes must be included in bandwidth calculations, and standards need to account for the difference in how BI-MMF guides light. The practice of neglecting these modes in a BI-MMF, as suggested by some manufacturers, can lead to an incorrect determination of modal bandwidth for laser based systems.

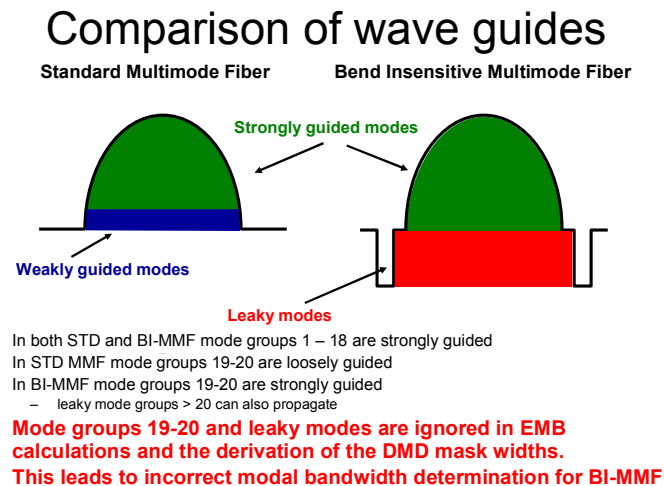


Figure 2

Measuring Bandwidth in Bend-Insensitive Fiber

Bandwidth requirements for high speed, short reach networks have evolved from the early days of Light Emitting Diodes (LEDs) to high speed Vertical Cavity Surface Emitting Lasers (VCSELs). With each successive increase in transmission speed, bandwidth requirements for multimode fiber have increased and loss budgets have gotten tighter. BI-MMF may improve the loss

budget in situations where tight bends are encountered (depending on added connector mating loss), but how do they affect bandwidth?

The data carrying capacity of a multimode fiber is a function of its modal bandwidth. The modal bandwidth specifications in the IEEE 10G, 40G, and 100G Ethernet standards were developed based on a sophisticated model predicting the performance of a VCSEL launch with a standard multimode fiber waveguide. These requirements were then translated into TIA specifications that are used to ensure that OM3 fiber will have 2000 MHz*km and that OM4 fiber will have 4700 MHz*km modal bandwidth in the deployed systems. However, the models used to develop bandwidth specifications in TIA are *not valid* for BI-MMF fibers, where light is guided differently in the fiber. Therefore, the bandwidth performance of these BI-MMFs is undefined in today's high speed networks. This is one of the greatest concerns with BI-MMF.

When the Differential Mode Delay (DMD) measurement and systems bandwidth model was developed to determine multimode fiber bandwidth, it was assumed that only the first 18 mode groups would propagate in the fiber, and that the 18th mode group would be highly attenuated. Therefore, the simulation modeling for both EMB and DMD mask widths used only 17 mode groups. BI-MMFs propagate both guided and leaky mode groups that are not accounted for in the current laser-optimized bandwidth calculations, and these modes can significantly degrade bandwidth if they are ignored. The potential result: modal bandwidth that is significantly lower than expected, leading to low link margins or even system failures.

To illustrate this problem, the DMD of the four commercially available fibers that clearly met the 4700 mHz* km Calculated Effective Modal Bandwidth (EMBc) requirement for OM4 were examined (see Figure 3).

DMD Measurements of BI-MMF Fibers with Comparable EMBc

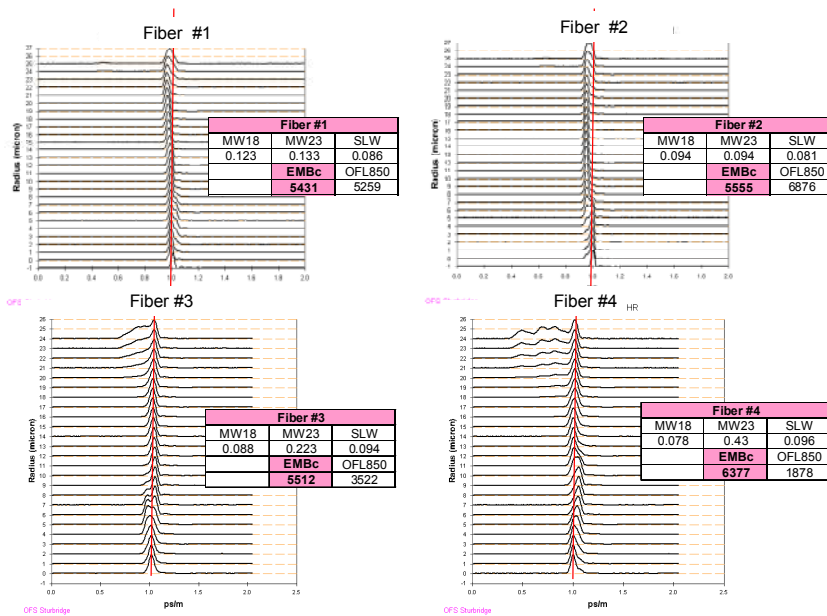


Figure 3

All fibers had comparable EMBc bandwidths, but Fiber #4 failed the DMD mask method of determining OM4 multimode fiber bandwidth. Both Fiber #3 and Fiber #4 had poor high order mode control, indicating poor control of the fiber core deposition near the core/cladding interface.

When inserted into a 550 m 10 Gb/s link, Fiber #3 and Fiber #4 performed poorly, while Fiber #1 and Fiber #2 performed as expected for OM4 fiber. Figure 4 shows that the system penalties for fibers with poor higher order mode control are significantly higher than fibers with good control of all modes. This variation in performance indicates that substantial work is required to properly classify bandwidth in BI-MMFs. Higher order modes (17th, 18th and higher mode groups) propagating in BI-MMFs can make system performance much worse than predicted by current standards.

The OFL bandwidth values illustrate the usefulness of this parameter to ensure system performance, but the current 3500 MHz-km requirement may not be sufficient to screen BI-MMFs because of their higher order mode behavior. Fiber #4 has good EMBc but failing OFL bandwidth,

and it has poor system performance. Fiber #3 has marginal OFL bandwidth and poor system performance, while the two fibers with high OFL values (>5000 MHz-km) have very good system performance.

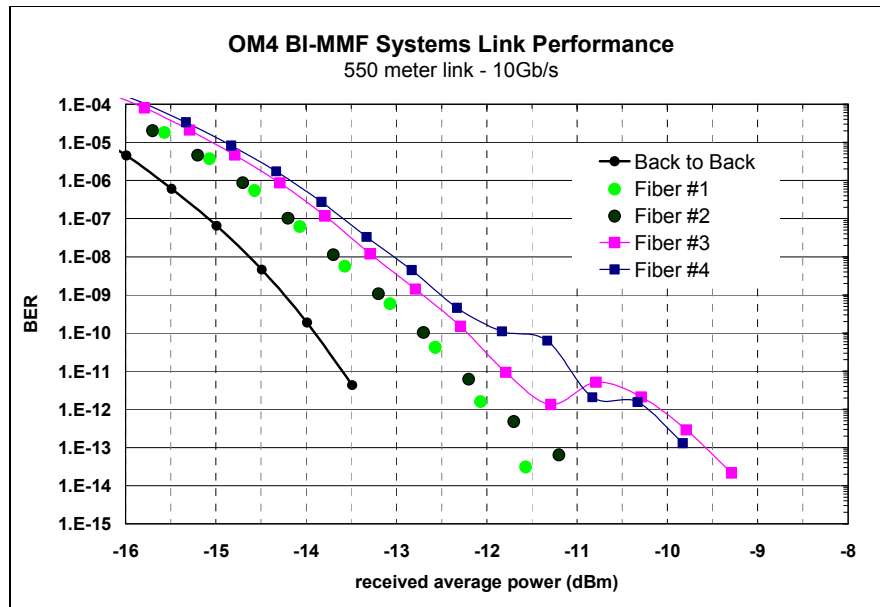


Figure 4

As more modes propagate, it becomes more difficult to achieve high bandwidths. This drove the market transition from 62.5/125 μm fiber to 50/125 μm fiber – fewer modes to control made it possible to develop a higher bandwidth fiber. This allowed fiber bandwidth to increase from 160 MHz*km required for FDDI to over 2000 MHz* km at 850 nm (OM3), and to 4700 MHz*km for OM4 fiber required by the current Ethernet standards. With more strongly guided higher order mode groups and additional leaky modes, BI-MMF may be a step in the wrong direction as we push towards 100 Gb/s Ethernet using 25 Gb/s lanes and 32 Gb/s Fibre Channel.

Mechanical Reliability

The mechanical reliability of an optical fiber jumper can be negatively affected by bending radius. Link reliability depends not just on optical robustness, but also on the mechanical strength of the components. BI-MMFs have the same mechanical properties as standard fiber and uncontrolled

sharp bends can cause mechanical failure. In other words, a sharp kink over a shelf edge, or a jumper caught in a cabinet door, significantly increases the possibility of a mechanical failure (bends such as these can approach 2 mm or less bend radius).

In single-mode bend-insensitive fibers, this was accommodated by a significantly larger 4.8 mm cordage diameter, which limits the fiber bend radius to roughly 5.0 mm. However, with a 2.0 mm jacket, minimum bend radius can be considerably less. Studies show

Failure Probability – No Tension			
	1.5 mm bend radius	1.75 mm bend radius	2.0 mm bend radius
month	100%	0%	0%
1 yr	100%	100%	0%
2 yr	100%	100%	0%
4 yr	100%	100%	1%
10 year	100%	100%	50%

Table 2

that bend radii of 2.0 mm or less have a large probability of failure. Any tension on the fiber creates additional stress and accelerates the failure rate significantly beyond those shown in Table 2. The addition of two pounds of tension increases the failure probability to 100 percent within one year (Figure 5).

Failure Probability - 2 Pound Tension

	2.00 mm bend radius	2.25 mm bend radius	2.50 mm bend radius
month	0.00%	0.00%	0.00%
1 yr	100.00%	0.02%	0.00%
2 yr	100.00%	0.61%	0.00%
4 yr	100.00%	2.06%	0.00%
10 year	100.00%	100.00%	0.15%
30 year	100.00%	100.00%	0.37%

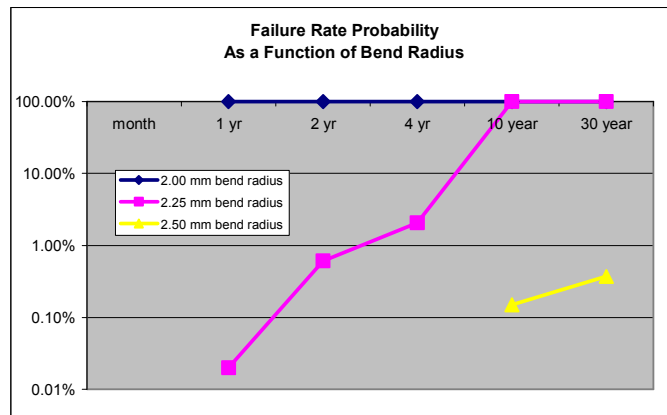


Figure 5

Increasing optical reliability provides no benefit to the end user if mechanical reliability can be compromised with poor installation practices. In fact, it can be argued that it is beneficial for a standard fiber to show high loss in systems with very tight bends, forcing the installer to correct these

poor installations to help ensure the robust performance of the system over the expected lifetime. An unexpected link failure six months after installation and system turn-up could cause catastrophic consequences in today's high performance data center.

Conclusion

There are many important questions about bend-insensitive multimode fibers. Issues regarding backward compatibility and bandwidth performance must be resolved before widespread deployment of this fiber occurs. System reliability, *including* mechanical reliability, is of critical importance to enterprise customers. Standards groups such as TIA are an excellent forum to study BI-MMFs and characterize their system performance. These industry groups can ensure that current and new standards accurately assess and verify the performance of next generation multimode fibers. In the meantime, the risk of uncertainty in the performance of BI-MMF outweighs the limited bending loss benefit they provide to enterprise cabling systems.