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White Paper

LaserWave® *FLEX* Bend-Optimized Fiber:

Innovative Design, Proven Performance

Multimode fiber using a graded-index waveguide has been deployed in communications networks for more than 30 years. In 2009, a new type of 50 µm multimode product called bend-insensitive multimode fiber (BIMMF) was introduced to the market. Some manufacturers introduced this product claiming that this fiber was fully compliant with the current OM2, OM3, and OM4 fiber standards, with the added benefit of improved macrobend performance.

Since that time, there has been considerable discussion and debate, both within and outside the standards bodies, about whether this new class of fiber is indeed a simple "drop-in" substitute for any system that uses 50 µm multimode fiber. The industry consensus: The performance of BIMMF is sufficiently different from standard multimode fiber, in terms of the way it carries light, to warrant changes to industry-standard fiber specifications.

In 2010, the industry formed a task group under the Telecommunications Industry Association (TIA) to study BIMMF. Led by OFS, this representative group of fiber, structured cabling, and test equipment manufacturers has made great progress in understanding the behavior of BIMMF and how it affects system performance. Most important, the group has agreed that measurement methods must be adjusted to ensure that no sacrifice in performance is experienced with BIMMF, and that BIMMF designs are fully interoperable (with each other as well as with standard 50 µm multimode fibers).

Although a new standard for BIMMF is not expected to be published until 2013, the technical study of system performance has progressed far enough that the industry has a good understanding of these products. As a result, OFS has been able to design and manufacture a fiber that is *optimized* for excellent bend performance while maintaining superior bandwidth and excellent connectivity with standard multimode fibers. To differentiate its fiber, OFS uses "bend-optimized" when describing the performance of LaserWave® *FLEX* Fiber, rather than the generic "bend-insensitive" industry term.

LaserWave *FLEX* Bend-Optimized Fiber is compliant with current standards and is designed to meet the expected requirements of the new standards. OFS uses proprietary measurement methods to make sure that connectivity and system bandwidth are consistent with standard OM3 and OM4 fiber for compatibility and system performance. This ensures that LaserWave *FLEX* fiber, like our standard LaserWave fiber, provides outstanding link performance.

Furthermore, LaserWave *FLEX* fiber provides "early warning" of risky bends so small they could lead to a fiber break.

Bend-Insensitive Multimode Fiber Designs

Bend-insensitive multimode fiber uses a graded-index profile similar to standard multimode fiber, but with an added design feature: It has an optical "trench" surrounding the core, effectively confining light within the core to improve its macrobend performance.

While the trench gives the fiber good bend performance, it also allows the propagation of what are called "leaky modes," which are not present in standard multimode fiber. These leaky modes (shown in red in Figure 1) can travel a few hundred meters in the fiber and can impact the characterization, or measurement, of several important properties of the fiber including core diameter, numerical aperture (NA), and bandwidth. Improper control and measurement of these leaky modes can lead to excess insertion loss and inadequate bandwidth.

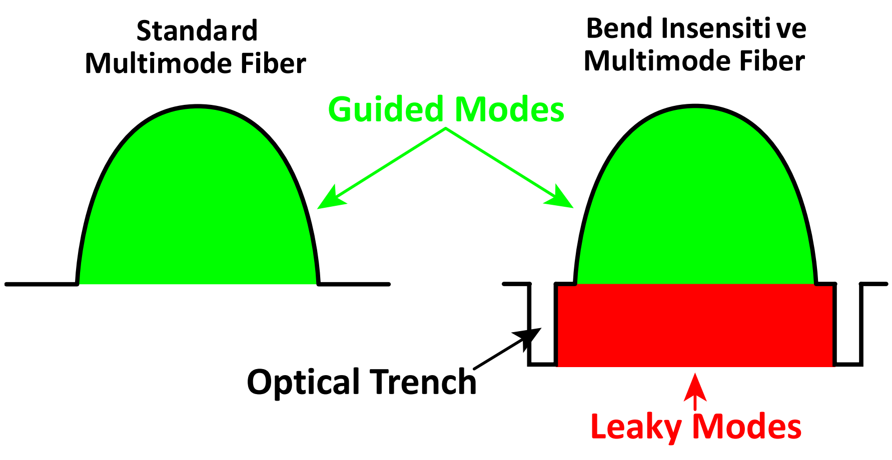

FIGURE 1: Comparison of standard and BIMMF graded-index profiles highlighting the optical trench and the leaky modes (shown in red) that are not present in standard multimode fibers.

Bandwidth Measurement Considerations

Bandwidth is a key attribute of multimode fiber. The Differential Mode Delay (DMD) test method currently used to measure bandwidth has a *minimum* sample length requirement which is determined by the resolution of the measurement system. No *maximum* length requirement was thought necessary for two reasons. First, it was originally assumed that performance over long lengths (> 1 km) was a reliable measure of short "system length" performance. Second, there are no leaky modes to worry about in standard multimode fiber.

However, subsequent work has shown that long-length measurement may not be a reliable indicator of performance. Also, with BIMMF, leaky modes can travel several hundred meters – the same kind of distances you would see in deployed systems.

To ensure OM3 and OM4 performance for BIMMF, OFS recommends that DMD measurement should be made on system-significant length samples of about 500 meters to account for weakly guided and leaky modes and to ensure they do not degrade bandwidth performance. In order to further safeguard BIMMF performance, we recommend the Calculated Overfilled Modal Bandwidth (OMBc) method to ensure that these weakly guided and leaky modes are well controlled.

In fact, OFS has always used shorter lengths to measure DMD of standard LaserWave fibers to take weakly guided modes into account. This provides a more realistic representation of actual system performance, compared to other fiber manufacturers who perform DMD measurement using samples that are several *kilometers* long.

Current standards requirements allow compliance to either the DMD Mask specifications or the Calculated Effective Modal Bandwidth (EMBc) specs. Studies have shown that the DMD Mask method is a more stringent screen of higher order mode propagation.

At OFS, we use *both* methods on our standard LaserWave fibers as well as our LaserWave *FLEX* fiber. This provides outstanding performance and reliability for today's demanding network systems. As a result, our LaserWave *FLEX* fibers perform to the level users have come to expect from our LaserWave family of products.

Geometry Considerations

Connectivity performance (connection loss) is directly related to fiber geometry – specifically, to core size and NA. Current multimode geometry measurement methods for standard fiber were developed with the assumption that no leaky modes were present. For example, standardized measurements for core diameter and NA are made on two-meter samples, a reasonable length to strip out leaky modes in standard multimode fibers. For BIMMF, however, leaky modes easily propagate over this short length, which can result in inaccurate measurement results. If current standardized measurements are used for BIMMF, leaky modes can cause an overestimation of core size and NA. If not corrected, this may result in higher connection losses.

To address the fact that leaky modes can travel several hundred meters in BIMMF, there is a proposal within the TIA task group to perform core diameter and NA measurements on longer sample lengths. Studies have shown that this increase in sample length produces core diameter and NA measurement values that correlate well with actual connectivity performance. This is illustrated in Table 1 and Figure 2 below.

Fiber Design	Core Diameter		NA	
	2 m	1000 m	2 m	1000 m
Standard 50 µm	50 µm	50 µm	0.20	0.20
LaserWave *FLEX* Fiber	51 µm	50 µm	0.21	0.20
Competitor BIMMF	50 µm	49 µm	0.21	0.19

TABLE 1: Comparison of core diameter and NA measurements of various fiber designs using short (2 m) and long (1000 m) sample lengths.

As indicated in Table 1, measurement of core diameter and NA on LaserWave *FLEX* fiber using long lengths shows excellent consistency in comparison with standard multimode fiber, while non-optimized BIMMF is not as consistent and compatible. The smaller core and lower NA measured in the 1000 m samples of non-optimized BIMMF lead to higher connection and splice loss when mated to fibers with nominal values for these parameters.

OFS performed a comprehensive connectivity / insertion loss study to evaluate performance of LaserWave *FLEX* fiber and non-optimized BIMMF when connected to standard multimode fiber. As part of this study, short (2 m to 2 m) and longer (300 m to 300 m) lengths were connected and tested for insertion loss to examine the effect of the leaky modes that can propagate several hundred meters in BIMMF.

Figure 2 shows that LaserWave *FLEX* fiber can provide more than 0.1 dB improvement in insertion loss compared to non-optimized BIMMF when connected to standard multimode fiber.

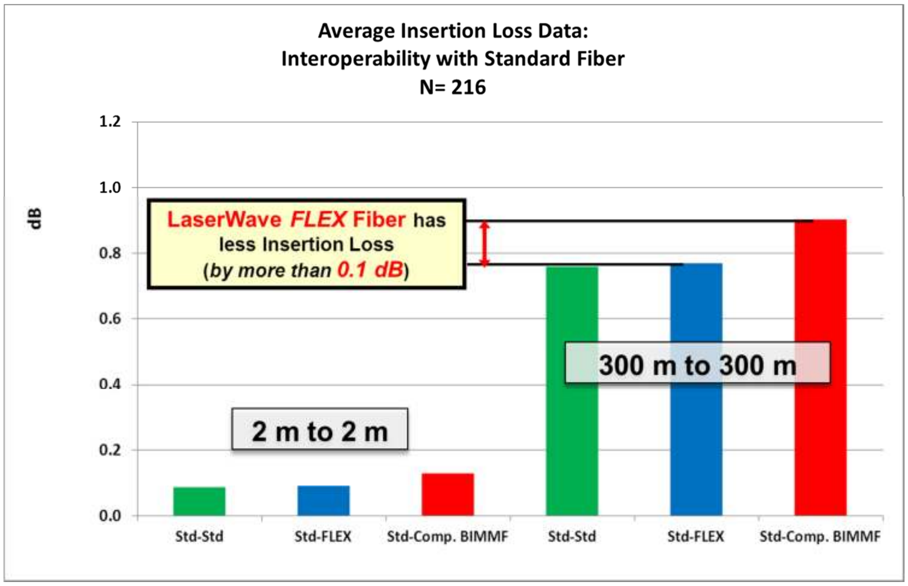

FIGURE 2: Comparison of insertion loss of LaserWave FLEX Bend-Optimized Fiber versus a non-optimized BIMMF and standard fiber.

Macrobend Performance and Mechanical Reliability

There is no question that macrobend performance improves significantly with bend-insensitive fibers like LaserWave *FLEX* fiber. For example, Table 2 shows that for 15 mm diameter bends, the macrobend specification at 850 nm improves by an order of magnitude compared to standard multimode fiber.

	Bend loss 100 turns 37.5 mm radius	Bend loss 2 turns 15 mm radius	Bend loss 2 turns 7.5 mm radius
Standard 50/125 multimode fiber	0.5 dB (850 & 1300 nm)	1 dB (850 & 1300 nm)	Not specified
Bend-insensitive 50/125 multimode fiber	0.5 dB (850 & 1300 nm)	0.1 dB (850 nm) 0.3 dB (1300 nm)	0.2 dB (850 nm) 0.5 dB (1300 nm)

TABLE 2: Comparison of proposed macrobend loss specifications for standard and bend-insensitive multimode fiber.

Even with its improved macrobend performance, BIMMF requires sound installation practices and maintenance of bend radius control in order to be used effectively. At bends approaching 5 mm radius or smaller, *all* fibers, including BIMMF, could become over-stressed and break prematurely. To put things in perspective, studies for Fiber-to-the-Home applications have shown that a 5 mm radius bend has a failure probability of about 10 ppm in 20 years. Failure rates quickly increase as bend radius decreases. At a 2 mm radius, a fiber is expected to fail within five years, and at 1 mm, it could fail *within a month*.

LaserWave *FLEX* fiber is optimized to prevent such over-stressed conditions. Low loss is maintained down to a 7.5 mm bend radius, but smaller bends (less than 5 mm) will result in a noticeable increase in loss. This is designed to serve as an "early warning" of a dangerous bend condition. These conditions can be encountered when a jumper is pulled over a shelf edge, pinched in a door, or knotted. LaserWave *FLEX* fiber is the *only* bend-insensitive multimode fiber that provides such "early warning" of very small-diameter bends that can lead to a catastrophic fiber break.

Figure 3 illustrates this "early warning" feature. It shows the risky bend region below 2.5 mm radius where failure probabilities become unacceptably high. Non-optimized BIMMF only shows a modest increase in loss of 1.2 dB or less at this tight bend. This may not raise any alarms during certification testing. With LaserWave *FLEX* fiber, you will see a noticeable loss of 3 dB or more, which should prompt action and investigation to ensure that no risky bends are present in the installation.

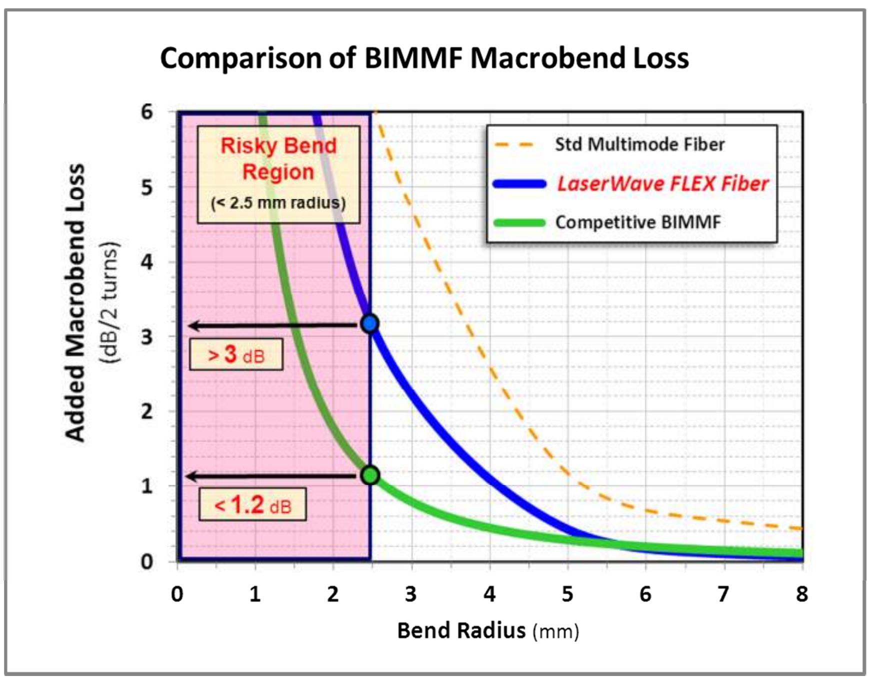

FIGURE 3: Comparison of macrobend loss between LaserWave FLEX Bend-Optimized Fiber versus a non-optimized BIMMF. "Early bend warning" is illustrated by higher loss seen in LaserWave FLEX fiber at risky bends (≤ 2.5 mm).

Summary

Bend-insensitive multimode fibers show improved macrobend loss in enterprise networks when compared to standard multimode fiber. This enables more compact fiber management systems and improved space utilization in modules, enclosures, cabinets, and patch fields. BIMMF can also help mitigate link failures when optical cables undergo small-diameter bends, particularly in jumpers and modules for data center and high-performance computer applications.

Although BIMMF can help maintain low-loss links under tighter bend conditions, it must not sacrifice connection loss and bandwidth performance. OFS' LaserWave *FLEX* Bend-Optimized Multimode Fiber is designed to maintain excellent low-loss compatibility with standard multimode fibers. Furthermore, OFS' proprietary MCVD fiber manufacturing process and dual DMD Mask/EMBc methods compliance provide better control of leaky modes when compared to non-optimized BIMMF. This helps ensure that LaserWave *FLEX* fiber maintains the same superior bandwidth performance as our standard LaserWave fibers.

Recent work in the standards bodies has shown that modifications in how fiber manufacturers measure bandwidth, NA, and core diameter are necessary to ensure that system performance is preserved when using BIMMF. OFS has implemented improved measurement methods in advance of the standard so that system performance and connection loss are not sacrificed.

With LaserWave *FLEX* Bend-Optimized Multimode Fiber, network owners and administrators will get the full benefit of a bend-insensitive multimode fiber with no sacrifice to other critical performance attributes such as connection / insertion loss and bandwidth. And for added peace of mind, LaserWave *FLEX* fiber is the only bend-insensitive multimode fiber that provides "early warning" of a risky bend that could lead to a fiber break.

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