Bending the Truth - Get the straight story about Corning® ClearCurve® multimode fibers

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Introduction

In 2009, Corning introduced ClearCurve® multimode fiber, the first standards compliant bend-insensitive multimode fiber (BIMMF) for high bandwidth 50 µm applications. As other manufacturers have entered the market, it has become obvious that there are significant differences in the performance of a well designed BIMMF fiber such as Corning's and some of the other product offerings.

The following article will help guide the reader to understand what important design considerations were taken into account during our journey to bring this product to market and what questions you should be asking about your BIMMF choice. The following topics should help the reader to better understand how a well designed BIMMF is fully standards compliant and backwards compatible to the installed base.

Corning ClearCurve multimode fiber is available in OM2, OM3 and OM4 bandwidth grades (defined per ISO/IEC 11801). During the development of ClearCurve multimode fiber, we quickly discovered that if we focused exclusively on bend performance, the development process would have been relatively quick and painless given our technology and manufacturing expertise. However, we weren't happy with just great bend performance. From the beginning we made it a requirement that the product we were developing had to be fully standards compliant, fully backwards compatible to the installed base (including all standards compliant multimode fibers – both Corning and competitors), and capable of the same high bandwidth OM3 and OM4 performance that our InfiniCor® 50/125 µm fibers provided. Significant efforts were focused on ensuring that bandwidth, Core Diameter (CD) and Numerical Aperture (NA), in addition to all other specifications, remained fully standards compliant.

Core Diameter Measurements

An example of a standards compliant high bandwidth bend-insensitive multimode fiber's graded index profile such as Corning ClearCurve multimode fiber is shown in Figure 1. The scan below is a transmitted near field power distribution when the test fiber is illuminated with an overfilled launch per IEC 60793-1-20. A near field intensity scan is a plot of measured power as a function of radial position in the fiber and the distribution echoes the core alpha profile of the fiber under test.

There are two standards-compliant ways to characterize the core diameter of a multimode fiber from the near field measurement. The 2.5% threshold method defines the core diameter at the point that the power is reduced to 2.5% of the normalized power. The 80/10 fit fits the data from the 80% normalized power to the 10% normalized power to a power law equation. The core diameter of Corning ClearCurve multimode fiber (50.0 ± 2.5 µm) is fully standards complaints to both methods.

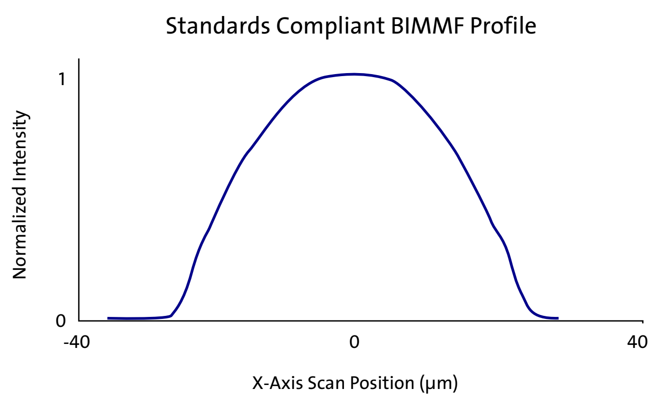


Figure 1

The near field power distribution for two other commercially available competitive BIMMFs are presented in Figures 2 and 3. These fibers are both billed as being fully standards compliant, but unfortunately that is not necessarily the case. The near field spectrum provides the best representation of where power actually resides in the fiber. The near field of the fiber in Figure 2 has shoulders that extend well beyond the physical core boundary failing the 2.5% threshold criteria. Additionally the near field in Figure 3 has localized peaks near the core boundary failing both criteria. As a result of these features, both of these BIMMFs have core diameters that may be higher than approved industry standards for a 50 μm fiber.

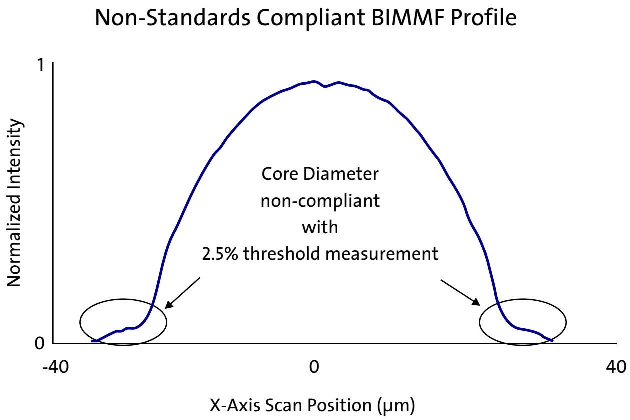


Figure 2

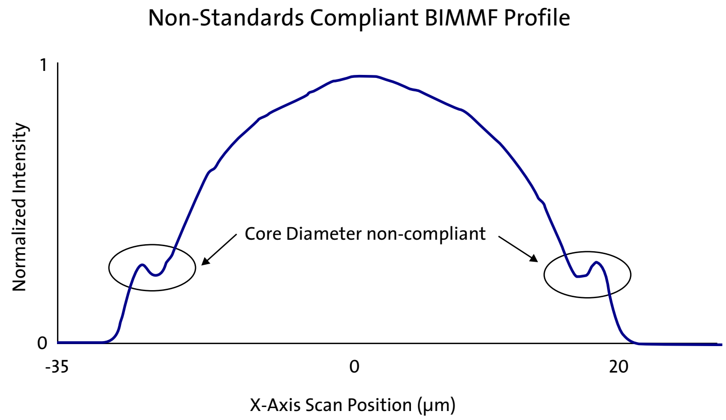


Figure 3

It is easy to understand how these fiber designs presented in Figures 2 and 3 might pose interoperability issues with either standard multimode fiber or well-designed BIMMF and also raise significant issues relative to OM3/OM4 selection criteria. The near field profile suggests the presence of additional power in the higher order modes that propagate outside of the core region. The additional power could affect interoperability when these fibers are coupled in homogeneous and heterogeneous lengths, particularly when there are misaligned couplers or splices in the system. Furthermore, the additional power in this radial position could affect the application of DMD mask templates. Several of these templates have lenient outer masks that may not appropriately account for the additional power in this region.

Numerical Aperture (NA)

NA is a measure of the acceptance angle of light that a fiber can support through total internal reflection as shown in Figure 4 below. It's basically a measure of how efficiently light is coupled into the end face of the fiber. The higher the NA, the more light can be captured by the core. In order to ensure compatibility between designs, it is critical that the NA remains standards compliant (i.e. 0.200 ± 0.015).

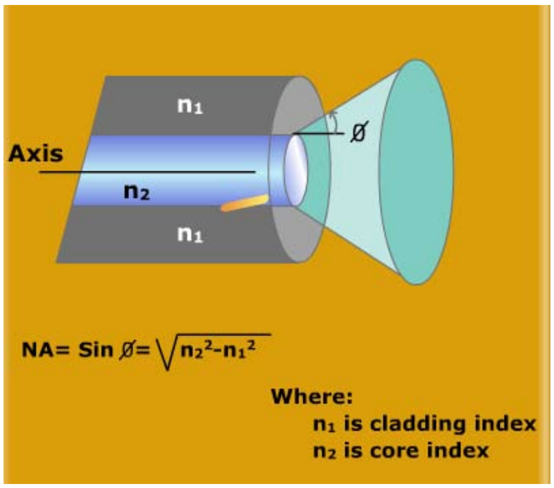
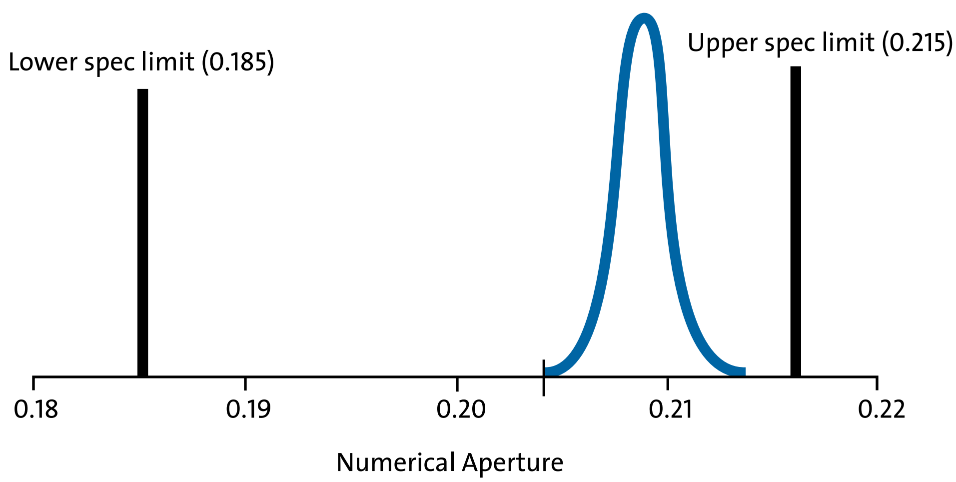


Figure 4

To understand the importance of NA, consider the light that is coupled into a typical multimode fiber with a traditional core and cladding design. The outer modes of this fiber are poorly guided, and some of the power coupled into the fiber is immediately lost to the cladding. When the fiber is bent, even more light escapes from the core and enters the cladding, and this leakage reduces the effective NA of the fiber. In contrast, in a BIMMF, these outer modes are more strongly guided, and this can result in a larger NA compared to a standard multimode fiber. In some cases, the NA will no longer be standards compliant unless additional modifications are made to the BIMMF design. Corning realized this tradeoff very early on in the design process and took the necessary steps to ensure that, even though the leaky modes are confined in the core, the NA is still fully standards compliant.

During the development of ClearCurve multimode fiber, Corning did extensive testing on all optical parameters and the NA was a focal point. Corning tested over 3500 samples (>>30 kkm) to ensure strict adherence to the standard and this is shown in Figure 5. Production data continues to show this same tight distribution. As you can see, the full distribution is within the limits of the standard.



Numerical Aperture Distribution Data
Figure 5

Interoperability and Backwards Compatibility

When developing and testing bend-insensitive multimode fiber it is important to consider not only laboratory testing to meet standards requirements but also testing that is representative of how the fiber will be used in an actual system. Areas of interest include splice loss, the performance of the fiber in connectors and the associated connector loss.

ClearCurve multimode fiber has minimal insertion loss when deployed with standards compliant legacy multimode fibers or other BIMMFs that are also standards compliant. In many cases, the loss performance associated with homogeneous splicing of BIMMF is superior to that of homogeneous splices of standard multimode.

Figure 6 below shows the fusion splice loss between ClearCurve multimode fiber and standard 50 μm (in this case Infinicor® SX+) fibers. You can see that in all cases the splice loss is well below the industry accepted value of 0.3 dB.

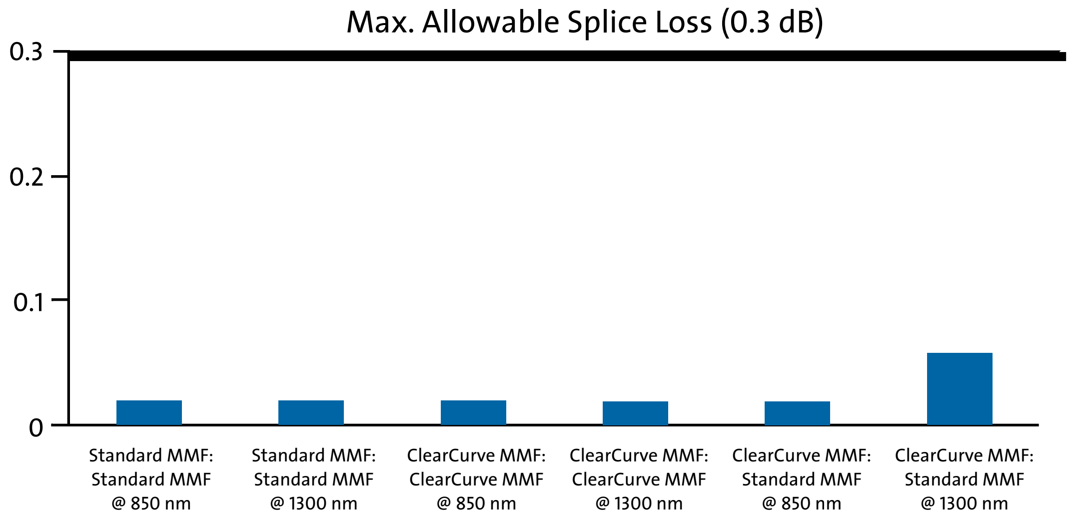


Figure 6

Figure 7 below shows the results of fusion splicing ClearCurve multimode fiber to several different standard 50 μm multimode fibers from different manufacturers. As one can clearly see, a well-designed BIMMF like ClearCurve multimode fiber provides equivalent loss performance to standard multimode fiber at 850 nm, where laser optimized systems are designed to operate. And although the 1300 nm performance may be slightly elevated in certain cases – it is again below the 0.3 dB that is widely accepted in the market.

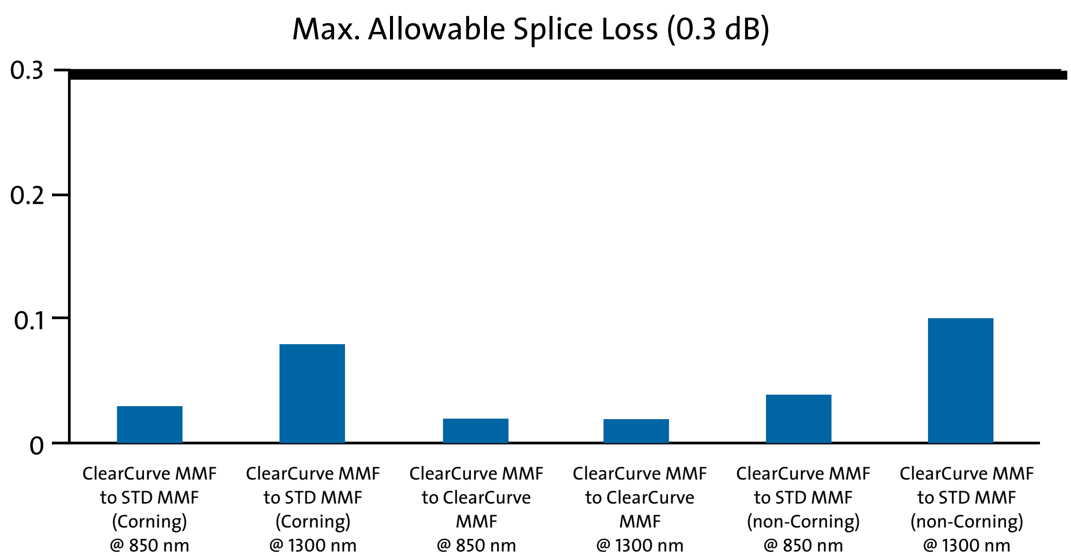


Figure 7

ClearCurve multimode fiber can be fusion spliced using existing procedures and equipment and is backwards compatible with standard 50 μm multimode fiber. Corning has conducted extensive splice studies as part of its rigorous qualification program. Testing to date has demonstrated excellent fusion splicing results in terms of low splice loss and high yields when splicing ClearCurve multimode fiber to itself or to other standards compliant 50 μm multimode fibers. This testing included standard 50 μm multimode fiber made by Corning as well as those made by other vendors. As shown in both tables, the test results are well below the maximum allowable splice loss (0.3 dB) per the TIA-568 standard and ISO 11801 standard.

During the development of ClearCurve multimode fiber, Corning also did extensive testing to ensure that the connector loss was not negatively impacted by the introduction of ClearCurve multimode fiber into any portion of the system. Some of the test results with ClearCurve multimode fiber actually pointed to a possible reduction in connector loss with ClearCurve multimode fiber as compared to standard multimode fiber.

ClearCurve multimode fiber can be terminated with standard single-fiber and multi-fiber connectors using existing connectors and procedures. Testing to date has demonstrated superior connector performance in terms of low connector loss and high yields for mated pairs connecting ClearCurve multimode fiber to itself as well as those connecting ClearCurve multimode fiber to another standards compliant 50 μm multimode fiber. Connector types have included both factory-installed and field-installed no-epoxy no-polish connectors.

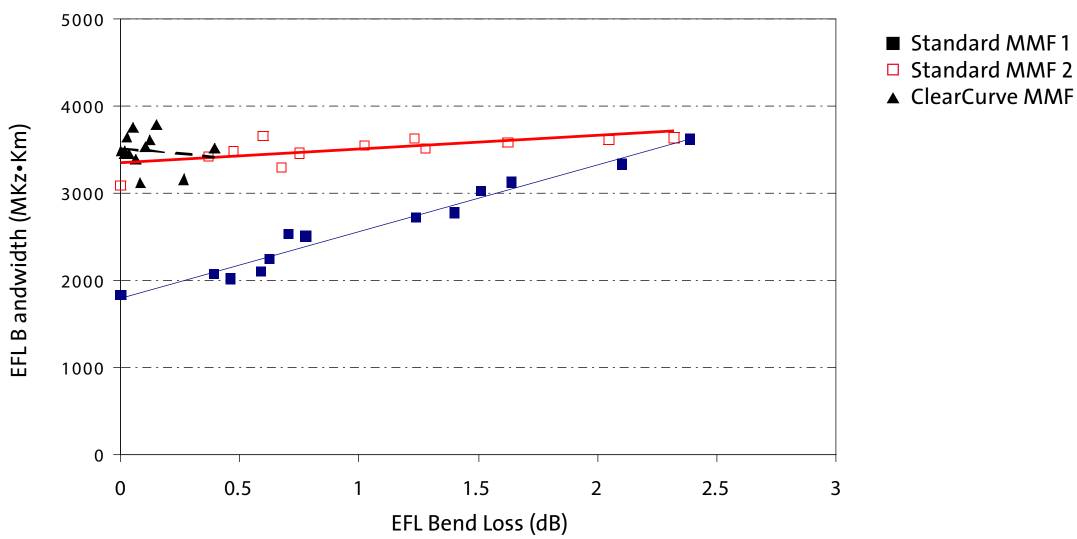
Testing was done with three external vendors and all results were similar. Results in Table 1 show zero indication of increased connector loss with ClearCurve multimode fiber. In fact two of the three cases actually showed an indication of a possible decreased connector loss with ClearCurve multimode fiber.

Table 1

	Average Connector Loss at 850 nm (dB)	
	Standard MMF to Standard MMF Average Connector Loss at 850 nm (dB)	Connections with at least one ClearCurve MMF Average Connector Loss at 850 nm (dB)
Lab A	0.1 to 0.2	0.1 to 0.2
Lab B	0.2 to 0.4	0.1 to 0.4
Lab C	0.09 to 0.13	0.03 to 0.07

No Trade Off Between Bandwidth and Macrobend Loss

We conducted a series of bandwidth and bend loss measurements to explore the impact of macrobend loss on bandwidth with an encircled flux launch (EFL). The macrobending was induced by using mandrels of different radii (r = 5 mm, 7.5 mm, and 10 mm) with different numbers of turns (1, 2, 5 and 10). The results are summarized in Figure 8. For Standard MMF1, as bend loss increases so does the bandwidth. For Standard MMF2, the bandwidth remains relatively unchanged under different bending setups. In both cases the bend loss increases by approximately 2.5 dB in the most challenging bend scenarios. Unfortunately, the bandwidth response of standard MMF to bending is highly dependent on the particular fiber/transceiver combination so increasing bandwidth with bend loss is not something that can be planned for or designed into a network. Therefore, the key testing we did with ClearCurve multimode fiber was to ensure that the bandwidth would be comparable to Standard MMF2 shown below (i.e. it wouldn't decline under challenging bend conditions.) The chart below verifies this hypothesis. The points are all clustered to the left of the graph since the bend-induced loss still remains low even for the most challenging bend conditions – and there is no negative impact on bandwidth as a result of bending.



Impact of Macrobend Loss on Bandwidth

Figure 8

Bandwidth Measurements

There are two standards compliant ways to characterize laser bandwidth for 10 Gb/s and higher performance for OM3 and OM4 multimode fibers: minimum calculated Effective Modal Bandwidth (minEMBc) and Differential Mode Delay - Mask (DMD-mask). Since the advent of laser optimized 50 μm multimode fibers it has been clear to Corning, the original architects of both the DMD measurement technique and the minEMBc bandwidth measurement, that minEMBc is the most precise, accurate and robust way to determine the bandwidth for OM3 and OM4 multimode fibers.

Both minEMBc and DMD-mask are based on the Differential Mode Delay (DMD) measurement. For a DMD measurement, a single laser is launched at 1 or 2 μm intervals across the core of the fiber, exciting a different set of modes with each launch. The series of temporal pulses collected at the end of the fiber are then compared against each other to determine the maximum differential mode delay (or DMD). Fiber manufacturers other than Corning generally stop at this point to compare the DMD output against a series of masks to provide a pass/fail value for the fiber. Corning, however, takes the measurement one step further. Having collected the DMD that characterizes the fiber, Corning then weights the collected delay profile using a variety of launch power distributions that represent the full range of all standards compliant VCSELs (some with more power launched near the center of the fiber core and some with more power launched near the edge of the core) to ensure that the fiber will work with all possible VCSELs. With this additional step, Corning can provide an actual worst-case laser bandwidth value, or minEMBc, to guarantee that the fiber will perform as expected (or better) with any standards-compliant VCSEL source. Since there is a lot of variability allowed in the VCSEL power distribution this is critical step to assuring systems performance.

BIMMFs are designed to tightly confine the higher order mode groups to minimize attenuation due to small radius bends. One potential side effect of this is a change in the light capturing characteristics of the fiber. Any significant changes in these characteristics could affect the functionality of attributes associated with OM3/OM4 fiber selection, such as EMBc weights and DMD-mask templates. The most direct method to assess the impact of the fiber design on transmitter launch characteristics is to assess the response of encircled flux (EF) to varying launch conditions. Encircled flux is the cumulative power within a given radius launched by a transmitter into a multimode fiber core. Differences in EF between a properly designed BIMMF and standard 50 μm multimode fiber should fall within the typical repeatability of the measurement. Figures 9 and 10 show examples of EF measurements of standard 50 μm multimode fiber and ClearCurve multimode fiber and the differences in EF with launch conditions that captures power distributions seen in commercially available VCSELs. The differences in nominal encircled flux that were obtained with these two different fiber types were within 1% under all launch conditions, as shown by the light blue line (labeled EF) in Figure 10. This variation is within the nominal variability of EF measurements of 1%. Since the EF values are similar, the EMBc weight functions will also be similar. This confirms that, minEMBc as currently defined, is the appropriate method to use to measure bandwidth of standards-compliant BIMMFs like ClearCurve multimode fiber.

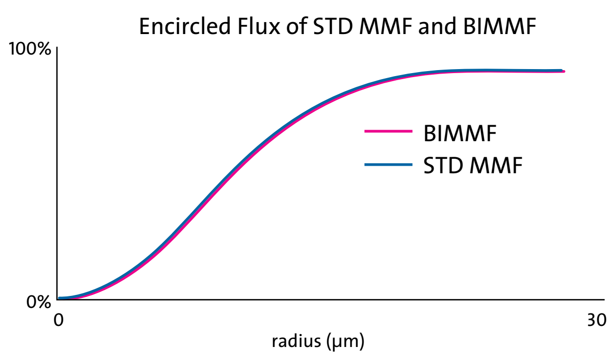


Figure 9

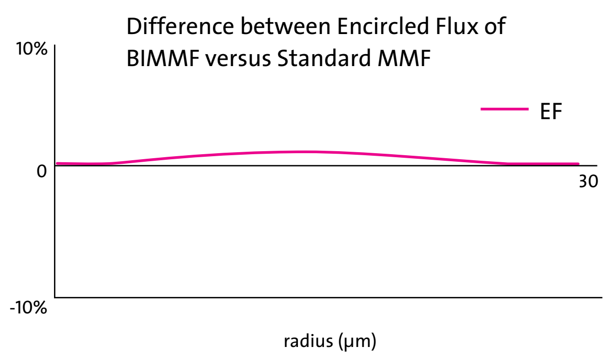


Figure 10

Some competitive BIMMF designs did not fare as favorably. As indicated in Figures 11 and 12, these BIMMF designs can yield significantly different EF values with up to 4% variance with the same launch condition. This variation in EF values is evident at multiple launch conditions, not just one. This is again proof that poorly designed BIMMFs will be subject to significant variations in power distribution. If there is more power in the outer mask region, it would seem that the very lenient outer mask for some of the templates, particularly templates 1 through 3 or 4 need to be re-visited. These variations could result in issues with fiber selection criteria. The variation in power distribution suggests that there could also be significant interoperability issues between standard 50 μm multimode fibers and poorly designed BIMMFs.

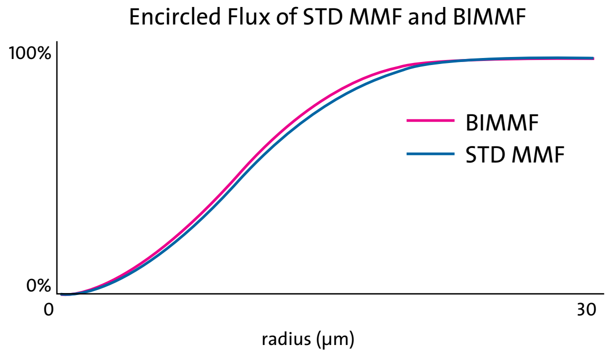


Figure 11

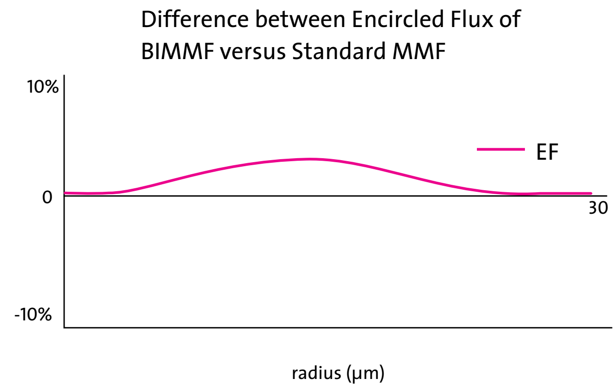


Figure 12

Applications Require BIMMF

Customers around the world face increasing demands on their data center and enterprise networks as a result of the ever escalating growth in high bandwidth applications. Therefore, private networks and data centers must operate as efficiently as possible while facing space constraints and density concerns. ClearCurve multimode fiber can help alleviate these problems by providing enhanced bend performance in a fiber that is OM2/OM3/OM4 compatible. The improved handleability of ClearCurve multimode fiber that comes as a result of the improved macrobend performance allows operators and designers to use cost effective multimode fiber solutions in more places in their enterprise network – displacing or replacing copper with a robust, high bandwidth transmission medium. Corning ClearCurve multimode fiber allows you to minimize the bend induced attenuation, thereby creating more operating margin. This will help to maximize system reliability and minimize downtime. Cablers and system integrators can take advantage of the improved bend performance in new cable, hardware and equipment designs. Now that bend sensitivity is much less of an issue, smaller and lighter cable, hardware and equipment designs are possible. These new designs will then provide additional cost savings by enabling smaller, denser, “greener”, easier to install data centers and premises networks.

Get the Straight Story on BIMMF

In summary a well designed BIMMF such as Corning ClearCurve multimode fiber complies with all relevant industry standards and adheres to the following criteria.

- ClearCurve OM2/OM3/OM4 multimode fibers are fully compliant and fully backwards compatible with all relevant industry standards;

Industry Standards	Fiber Product		
	ClearCurve OM4	ClearCurve OM3	ClearCurve OM2
ISO/IEC 11801	Type OM4 fiber	Type OM3 fiber	Type OM2 fiber
IEC 60793-2-10	Type A1a.3 fiber	Type A1a.2 fiber	Type A1a.1 fiber
TIA/EIA	492AAAD	492AAAC-B	492AAAB-A
ITU	G.651	G.651	G.651

- ClearCurve multimode fiber is fully backwards compatible and may be used with the existing multimode installed base
    - All other standards compliant 50/125 μm grades including OM2/OM3/OM4
- ClearCurve multimode fiber may be spliced or connectorized to conventional 50/125 μm fiber types or other standards compliant BIMMF with commercially available equipment and established practices and methods; no special tools or procedures are required.

Corning ClearCurve bend-insensitive laser-optimized multimode fiber delivers the best macrobending performance in the industry while maintaining compatibility with current optical fibers, equipment, practices and procedures. ClearCurve multimode fiber is designed to withstand tight bends and challenging cabling routes commonly found in data centers and other enterprise network environments. With greater signal protection when subjected to tight bending, ClearCurve multimode fiber offers greater system security and reliability meaning less system downtime and lower costs. Building on the proven bandwidth capability of Corning InfiniCor fibers, ClearCurve multimode fibers increase your capacity to succeed. Several hundred thousand kilometers of ClearCurve multimode fiber have been deployed all around the world with no reported issues.

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