j-BendAble – j-fiber's compatible bend-insensitive OM2/OM3/OM4 fiber series

j-fiber Jena

Member of LEONI Group

History

For decades, multimode fibers with graded index profiles have successfully been used for data transmission. The most commonly used fiber types have thereby been those with 62.5µm and 50µm core size diameters.

62.5 µm standard fibers have thereby been developed with focus on operation in the 1300 nm window. They allow data rates of 10 Mb/s to 100 Mb/s (usually referred to as OM1) launched with an LED source. Fibers with a 50µm core size diameter (usually referred to as OM2) have been optimized for launch with a narrow band laser source which allowed data rates of 1000 Mb/s over up to 2000m link lengths.

Paradigm shift

Around 2002 an unexpected paradigm shift happened. Extremely fast, price-attractive, narrow band laser sources from the entertainment industry, now presented an available low-cost light source option which allowed the transmission of significantly higher data rates.

A huge progress! However, these new VCSEL type lasers operated at 850 nm while existing fiber types had primarily been optimized for 1300 nm operation. To respond to the 850 nm wavelengths requirements, new fiber types had been developed which had their bandwidth maximum at 850 nm. The specific beam characteristic of the VCSEL required an optimized refractive index profile of the fiber as well as a different method to measure the fiber's bandwidth, the DMD measurement method *(More details on DMD measurement in Chapter "Compatibility – transmission features")*.

The result of these developments in fiber design and fiber measurement was a completely new fiber type: the OM3 fiber, which now provided for 10 Gb/s data rate transmission over up to 300 m distances, followed by the introduction of the OM4 fiber featuring the same data rate transmission performance but covering up to 550 m link lengths.

A major benefit of this innovative fiber type was its backward compatibility. Specifically in data center applications OM3 fibers enabled the smooth migration from 100 Mb/s to 10 Gb/s transmission and today are the dominant fiber technology used in this field.

Evolution

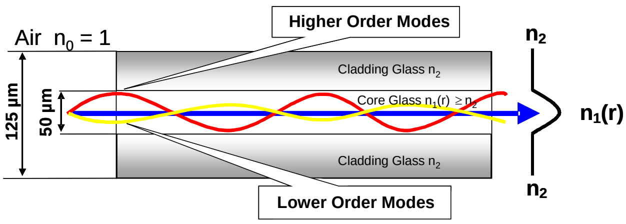
OM3/OM4 fibers are and will be the perfect fiber technology to meet the requirements of advanced applications today and in the near future. However, advances in data center technologies always aim at higher transmission speeds and increased data rates. New concepts discuss serial transmission of 25 Gb/s and more over one single fiber as well as parallel transmission solutions of 40 or 100 Gb/s over several fibers. Significant reductions of IT component sizes (50%) are being discussed as well.

Consequently, the interface and connectorization technologies ("patch field") as well as the fiber cables ("patch cords") will have to meet smaller space budgets. These tight space limitations for the IT infrastructure automatically lead to cable and thus fiber to cope with smaller bend-radii.

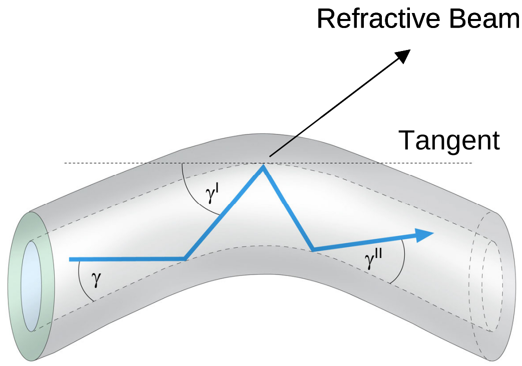
In a given system, the parameters „bandwidth" and „power budget" are connected. Therefore the system's total attenuation is a critical factor. Recent estimations indicate that additional attenuation caused by a number of bending turns at small radii can potentially increase the bit error rate (BER).

Fiber bending

The principle concept of an optical wave guide describes a light guiding core that has a higher index of refraction than that of its surrounding cladding. The difference in refraction indices determines the so called acceptance angle, which limits the angle in which light can be launched in and guided through the wave guide.
At its specific operation wavelength a multimode fiber guides approximately 100 modes (50 µm core diameter), resulting e.g. from the different angles by which the light has been launched.



What happens in case of bending the fiber? To explain it in a very simplified way: the fiber loses energy, the attenuation increases.



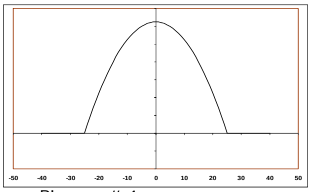
The reason: higher modes are not being guided through the fiber parallel to the fiber's axis but in a specific angle. Bending the fiber axis itself in a specific angle, the modes can no longer be guided and vanish.

To minimize this loss, a „barrier“ must be inserted. This can be done by integrating an additional structure that has a reduced index of refraction. Those modes that had left the core's area can than no longer leave the fiber. Usually, the additional structure, the so called “trench”, can be achieved by fluorine doping.

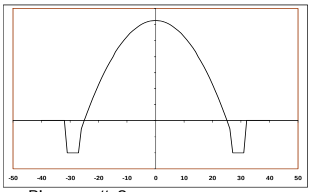
Bend Insensitive Multimode Fibers - BIMMF

„Bend Insensitive Multimode Fibers“ have been developed as a solution that considers these aspects in a modified fiber concept.

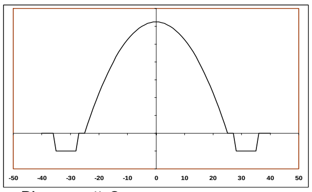
At j-fiber we have examined the currently commercially available fibers and found several variations in fiber design concepts.



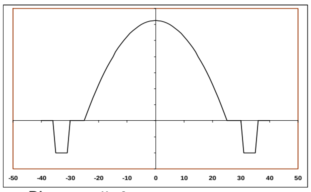
Picture # 1



Picture # 2



Picture # 3



Picture # 4

Picture #1 shows a standard graded index profile as applied in all current multimode fibers. Pictures #2-4 show different forms of implemented „trench“ designs.

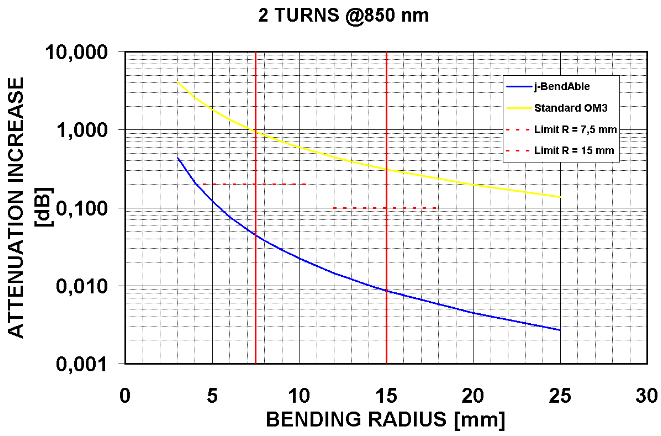
The question that quickly arises when looking at these different fiber designs is how the design effects the bending performance.

Bending performance

All concepts follow the aim to minimize attenuation loss in fiber bending. For realistic fiber behavior results when using VCSEL as light source, the macro bending performance is determined by the EF “Encircled Flux” launch instead of overfilled launch which would cause higher attenuation values.
Currently the following new specifications for the Multimode fiber standard IEC 60793-2-10 are being discussed:

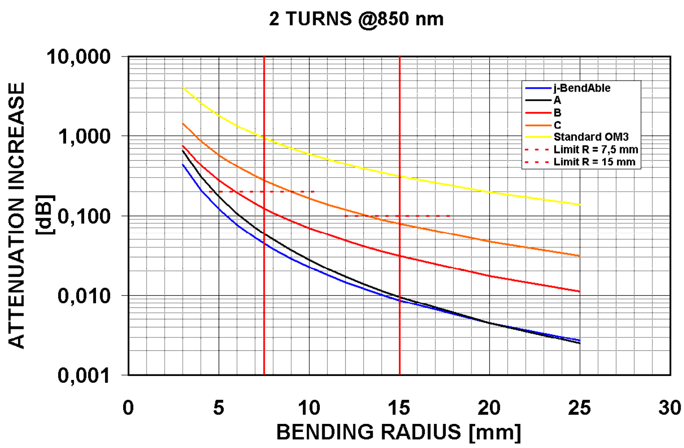
Maximum macro-bending loss [dB]					
Bend radius	# turns	Standard MMF 50 µm		BI-MMF 50 µm	
		850 nm	1300 nm	850 nm	1300 nm
37.5	100	0.5	0.5	Not defined	Not defined
15	2	1	1	0.1	0.3
7.5	2	Not defined	Not defined	0.2	0.5

We applied the function: bending radius versus attenuation increase to show the bending performance of our j-BendAble OMx. This very typical graphic points out two effects:



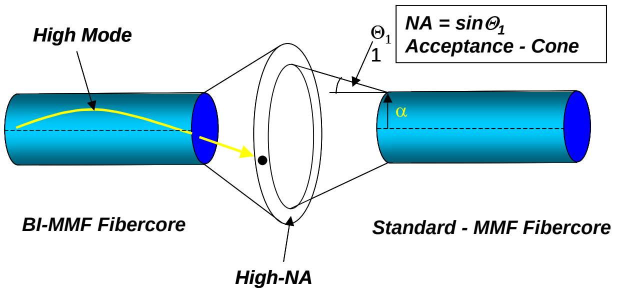
- j-BendAble OM2/OM3/OM4 shows a 20 times reduced bending attenuation at 7.5 and 15 mm bend radii compared to a standard fiber MMF
- j-BendAble OM2/OM3/OM4 exceeds the requirements given in the standard by factor 5 to 10.

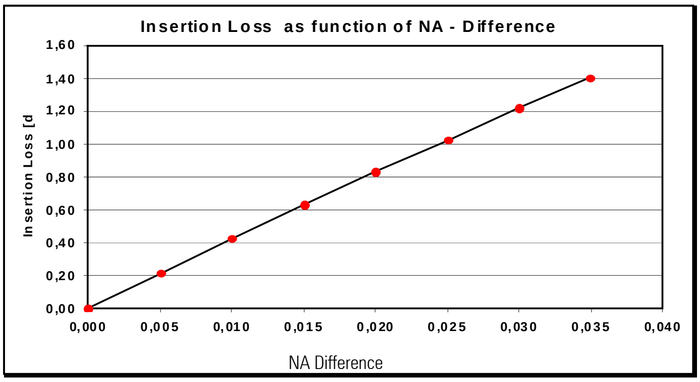
j-fiber has compared all currently commercially available BIMMF with very interesting results.
The measured range between the best and the least performing fiber was a factor 10 difference in attenuation. j-BendAble OMx thereby was among the top performers.



Compatibility – Splice loss

If two different fibers are being connected, either in a thermal splicing process or with a connector, their local core diameters and acceptance angles (key word: numerical aperture, NA) should be as similar as possible. If not, unwanted severe splice loss[i] is likely.

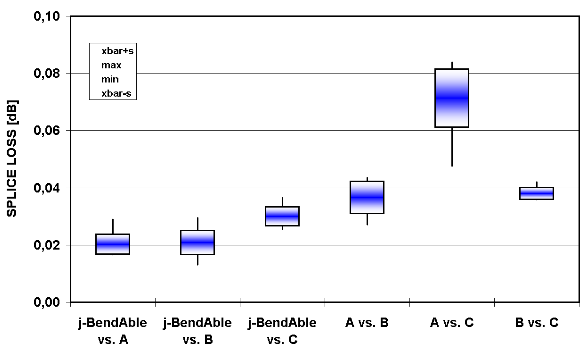




One requirement in fiber design demands to meet the specifications for core diameter and NA as closely as possible. This e.g. means to choose the appropriate trench position and design in the profile, a design parameter with very significant effect on the splice loss.
j-fiber has conducted several splice loss measurements by using an OTDR. In the following fiber set-up:

j-BendAble fiber ←→ BIMMF product from other vendor ←→ j-BendAble fiber

we measured the splicing performance on both sides and averaged the result.

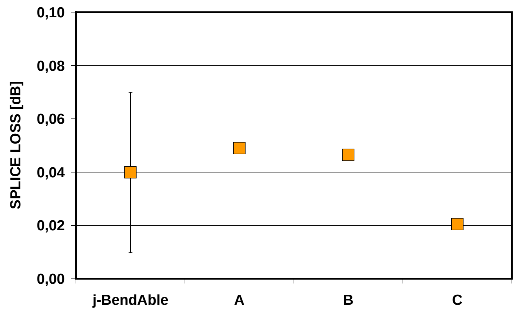


The experiments have been conducted by use of a commercial splicing tool and by applying the standard multimode program of the splicing tool.

We received two important results:

- j-BendAble OM2/OM3/OM4 reliably shows lowest splice loss when being spliced to other vendors' products
- Although all attenuation values lie within the tolerance range, there are obviously unfavorable combinations among the vendors' products.

A further test has been conducted to measure j-BendAble being spliced to a j-fiber OptiGrade OM3 fiber (a standard OM3 fiber) as well as other available BIMMF which have been spliced to an OptiGrade OM3 fiber



We received the following results:

- Within the standard deviation shown as example on the first point, the splice losses are identical

Compatibility – Transmission performance

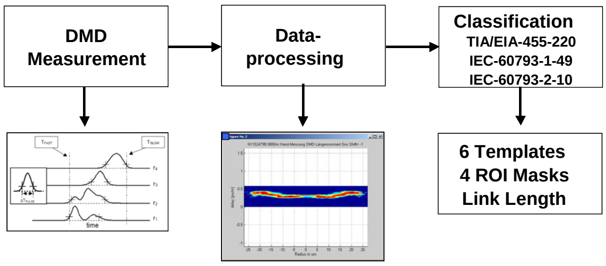
A relevant criterion for a fiber's transmission performance is its ability to guarantee for a 10 Gb/s link length. The "classic" overfilled launch bandwidth measurement is thereby mainly being applied for reasons of backward compatibility.

The relevant method to determine a multimode fiber's transmission performance is the so called (DMD Differential Mode Delay) measurement method and - based on it - the OM3 performance classification utilizing the mask and the calculated modal bandwidth (minEMBc) methods.

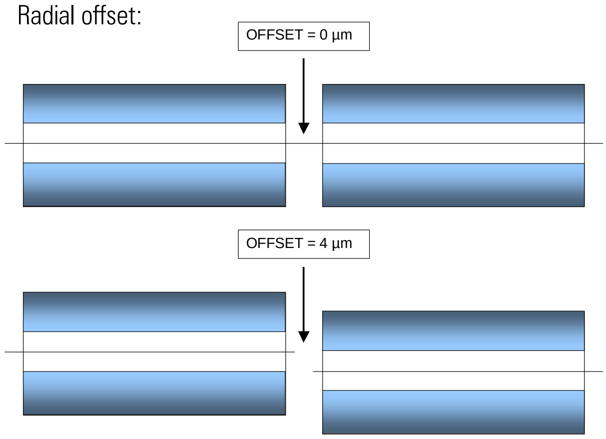
To conduct a DMD measurement a 5 μm light spot traverses in small steps across a fiber's core while run time measurements are being made at each position. The results allow the evaluation of run time differences in defined areas of the core.

We thereby examined three aspects in more detail:

- What happens to the transmission performance of the fiber when increasing the misalignment of the cores' centers by 0, 2 or even 4 μm?
- How good is the transmission performance when coupling j-BendAble OMx and available BIMMF products of other vendors?
- What happens if short pieces of all available BIMMF brands are being connected to a fiber of 300m length?



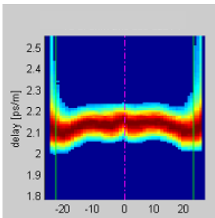
Radial offset:



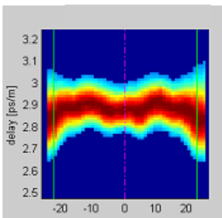
Fiber 1 Fiber 2

Coupling tests with other fiber brands by using different radial offsets:

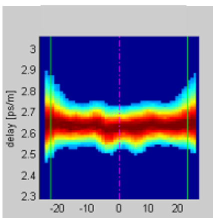
Fiber	10Gb/s Link Length [m]	EMB_C [MHz·km]
j-BendAble 1	597	3936
j-BendAble 2	713	5609
Offset 0 µm	689	6281
Offset 2 µm	638	6605
Offset 4 µm	671	6831



Fiber	10Gb/s Link Length [m]	EMBC [MHz·km]
j-BendAble 1	597	3936
Manufacturer A	528	4534
Offset 0 µm	669	4561
Offset 2 µm	691	4607
Offset 4 µm	668	4277

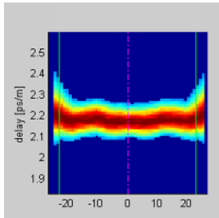


Fiber	10Gb/s Link Length [m]	EMBC [MHz·km]
j-BendAble 1	597	3936
Manufacturer B	713	81604534
Offset 0 µm	686	5628
Offset 2 µm	675	5102
Offset 4 µm	686	4726



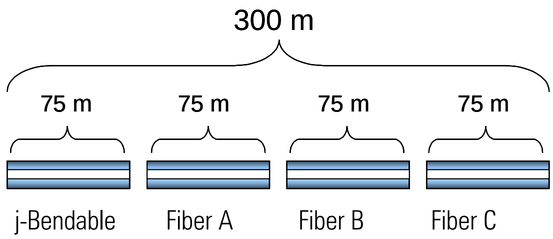
Core radius (µm)

Fiber	10Gb/s Link Length [m]	EMBC [MHz·km]
j-BendAble 1	597	3936
Manufacturer C	705	8185
Offset 0 µm	713	8164
Offset 2 µm	713	9046
Offset 4 µm	713	8422

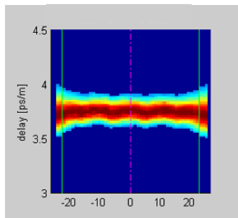


core radius (µm)

Concatenation test with a 300 m fiber link consisting of 4 BIMMF from different vendors, each of them of 75 m length.



Fiber	10Gb/s Link Length [m]	EMBC [MHz·km]
j-BendAble 1	597	3936
Manufacturer A	528	4534
Manufacturer B	713	8160
Manufacturer C	705	8185
Link Totals	713	8359



Summary of the results gained from all tests and measurements:

- j-BendAble OM3 fiber is truly compatible with all other fibers
- In all cases the link lengths of the combined fibers is equal or higher than the lowest single value (key word: mode mixing)
- The EMBc values showed a similar but less consistent behavior
- Even in case of a radial offset between the coupled fibers the required transmission specifications have been fulfilled.
- The table as well as the DMD graphic quite clearly show that j-BendAble OMx smoothly connects to other fibers. The OM3 performance in connected fibers is unaffected.

At the end now the topic with literally maximum “tension”:

Fiber Life Time

One of the most critical questions for potential users of BIMMFs refers to fiber life time: Will smaller bend radii – although possible and allowed in terms of optical characteristics – bear a new risk: FIBER BREAKAGE?

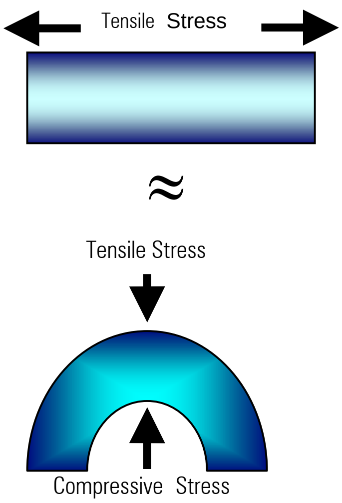
The experience from using wave guides for quite a long time, has confirmed a rule of thumb: when using and processing optical fibers their exposure to stress should not exceed 1/3 of the impact level as applied in screening tests.

It is a fact, that during the long period of using optical wave guides only a very small number of fiber breakages has occurred without finding a reasonable explanation (such as wrong handling, mechanical overexposure).
It is also a fact, that the fiber’s tension at a usual bend radius of 30 mm shows comfortable 0.15 GPa which equals 20% of the proof tension.
If the fiber has to withstand the impacts from bending at a 7.5 mm radius, the mechanical tension reaches a value of 0.6 GPa which is already 85% of the test proof tension.

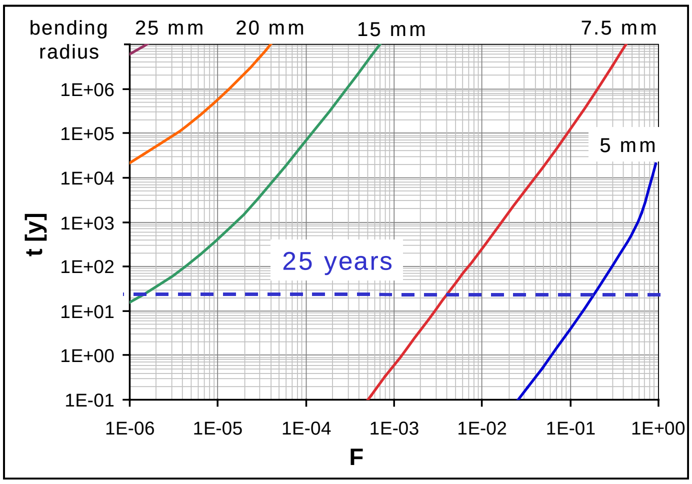
What does this mean for our rule of thumb which has so far been a good guideline to minimize the risk of fiber breakage?

Breaking the rule of thumb – consequences?

Fiber aging under tension follows the law that there is no difference between tension from pulling and tension from bending. Important: Under bending tension the affected fiber length is <u>not</u> identical with the length of the bow. Looking along the fiber’s cross section shows that only a small area is indeed being exposed to tension from pulling. Bending the fiber e.g. by 90° at a bending radius of 7.5 mm results in a bow of 12 mm length. But: the equivalent length under tension is only approximately 0.5 mm.



Based on the theoretical findings we can now make estimations about fiber life time and receive the following results:



F = failure probability for a uniformely bended fiber of 1m length

Conclusions based on these results:

- At a bending radius of 25 mm and larger and a fiber length under tension of 1 m the risk of fiber breakage within 25 years can be neglected.
- At a bending radius of 7.5 mm and a fiber length under bending stress of less than 1 m the risk of fiber breakage within 25 years is approximately 1 permille
- But: in case of an unintended bending radius of 5mm and under the same conditions as above, the risk of fiber breakage within 25 years increases to approximately 1%

In summary: The risk of fiber breakage in bending applications is no longer „nearly zero“, but calculable.

As a consequence of the results we received from these estimations we have changed the proof tension for our j-fiber data sheet from 100 to 200 kpsi (0.69 GPa to 1.38 GPa) and have increased the n_D value from ≥ 18 to ≥ 23. This value describes the aging of fibers under tension and acts as exponent in the life time calculation.

Summary

We have examined and discussed key aspects that are relevant for users of bend-insensitive multimode fibers in advanced data cabling:

- Lowest bending attenuation: 20 times better compared to standard multimode fibers and at a top position compared to other BIMMF vendors' products
- Lowest splicing attenuation, best compatibility compared to all other available BIMMF products
- Low splicing attenuation and best compatibility compared to standard MMF
- The fiber is insensitive to radial offset – a key benefit for cable termination
- Full compatibility for 10 Gb/s transmission compared to available BIMMF products
- Calculable failure risk because of modified process with higher n_D value and optimized coating system

Conclusion

There are good reasons to choose j-BendAble OMx when comparing the fiber to the market's available BIMMF products.

---

[i] Intermateability of Bend Insensitive Multimode Fiber with Standard Multimode Fiber
R. Pimpinella, B. Lane, Panduit Laboratories, Panduit Corporation
Proceedings of the 59th IWCS, 444 – 450

WP-NB-001-00-1111 Issued November 2011

Copyright 2011 © j-fiber GmbH with regard to DIN ISO 16016
Officially registered facility according to EWG No. 1221/2009

j-fiber GmbH
Im Semmicht 1
D-07751 Jena, Germany
Tel.: +49-3641-352 100
Fax: +49-3641-352 101
Email: info@j-fiber.com
Internet: www.j-fiber.com