

**Optical Fiber
Loss Testing**

Optical loss testing in the field is not as simple as it seems.

Abstract

Optical loss testing of multimode fiber can be affected by many variables, including fiber mismatch, the type and quality of the test reference cords and the launch conditions for launching light into the fiber under test. This white paper will look at how these different variables can affect the optical loss performance of a link under test. The results of a controlled experiment show that optical loss measurements using an “overfilled launch light source and a mandrel wrap as a mode conditioning filter” exhibit significant variance depending on the test equipment. The same tests performed using an Encircled Flux (EF) test method, provide close agreement between different test instruments. Encircled Flux is the test method recommended by industry experts for accurate optical loss measurements for both regular multimode fiber and bend-insensitive multimode fiber. This is particularly important for high speed applications that have tight optical loss budgets. Encircled Flux is the test method specified for 40G and 100G Ethernet applications.

Optical Loss Testing - Why It Is Important

Providing an accurate method for optical loss testing of multimode fiber is becoming a lot more important for higher data rate applications that place more stringent requirements on the maximum allowable loss for a channel between an optical transmitter and an optical receiver. As an example, Table 1 below shows the optical loss budget and the maximum reach for different applications.

Table of Contents

Abstract 1
 Optical Testing - Why It Is Important 1
 What Factors Affect The Accuracy of 2
 Optical Loss Testing?
 TIA Adopts Encircled Flux in New 5
 Fiber-Test Standard
 Comparative Optical Loss Measurements . . 5
 Using OFL/Mandrel Wrap
 Measured Results 6
 Some Good News! 6
 Summary, 6

Ethernet	OM3 IL max. (dB)	OM4 IL max. (dB)	Ethernet	OM3 Reach (m)	OM4 Reach (m)
1000BASE-SX	4.5	4.8*	1000BASE-SX	Note 1	Note 1
10GBASE-SR	2.6	3.1*	10GBASE-SR	300	Note 1
40GBASE-SR4	1.9	1.5	40GBASE-SR4	100	150
100GBASE-SR10	1.9	1.5	100GBASE-SR10	100	150

Table 1 - Optical loss budget and supportable distances for different applications.

*TIA 568-C.0-2 draft

Note 1: At the time these applications were developed the maximum distance for 1 GbE was 550 m and for 10 GbE was 300 m. Longer lengths may be possible on OM3 at 1 GbE and on OM4 at both 1 GbE and 10 GbE depending on the specification parameters assumed. Contact your manufacturer for supportable link lengths on specific applications

The higher the data rate, the tighter the loss budget for a channel. The maximum allowable loss for a 10Gb/s Ethernet channel over OM3 multimode fiber is 2.6 dB. The maximum allowable loss for a 40 Gb/s and a 100 Gb/s Ethernet channel is 1.9 dB over OM3 fiber and 1.5 dB over OM4 fiber.

What Factors Affect The Accuracy of Optical Loss Testing?

There are several major factors that can affect the testing accuracy for optical loss measurements. These include:

1. The type and quality of the “test reference cords”
2. Fiber mismatch between the test reference cords and the link under test
3. The characteristics of light source and how light is coupled into the fiber
4. The mode conditioning filter that is used

This article will look at the effect of all these different factors on the accuracy of optical loss measurements.

1. The type and quality of the “test reference cords”

The type and quality of the “test reference cord” is critical for accurate optical loss measurements in the field. The end-face geometry of the polished ferrule on the cord connector can have a significant effect on the test results and must meet precise parameters such as radius of curvature, apex and fiber protrusion. For this reason, the test reference cords need to comply with end-face geometry requirements such as those specified in Telcordia GR-326 standards. Also, the optical loss performance can be greatly diminished when the surface of the cord connector is scratched or simply dirty. Inspect the fiber connector with a fiberscope and clean the connector if it is dirty with a dry cleaning technique.

How do you know if your optical loss test results are reliable? An easy way to check is to test a “known good patch cord” that has been tested in the factory. Most patch cord manufacturers indicate the actual loss value on the packaging of their patch cords. Inspect and clean the patch cord connectors. Connect this “known good patch cord” to your equipment as if it were a fiber link and

Dimensional specifications								
Sectional sub-clause	Attribute	Test procedure(s), FOTP-	Performance requirements and test conditions	Qual. appr. & periodic regual.		QCI method ¹⁾		
				Sample size	Freq.	Code	Level	
a) → 4.2.1	Core diameter	176	50 ± 2.5 μm	N/A	N/A	SI	1.0	
4.2.3	Cladding diameter	176	125.0 ± 2.0 μm	N/A	N/A	SI/DPC	1.0	
b) → 4.2.5	Core/cladding concentricity error	176	≤ 3.0 μm	3	Annual	PR	NR	
Optical specifications								
Sectional sub-clause	Attribute	Test procedure(s), FOTP-	Performance requirements and test conditions	Qual. appr. & periodic regual.		QCI method ¹⁾		
				Sample size	Freq.	Code	Level	
c) → 4.4.7	Numerical aperture	177	0.200 ± 0.015	N/A	N/A	SI	1.0	

Table 2 - TIA-492AAAD specifications for OM4 Fiber, September 2009

test it using the same test reference cords that are normally used for link testing. Compare the measured result in the field to the loss value of the factory tested patch cord. If the result is significantly different (greater than 0.1 dB), there is something wrong with the field test. It can be your equipment, your test method or most likely, your test cords.

2. Fiber mismatch between two optical fibers that are joined together

Fiber mismatches are the result of inherent fiber characteristics and are independent of the techniques used to join the two optical fibers. The intrinsic coupling loss due to fiber mismatch, include among others:

- 2.1. core diameter differences
- 2.2. core/cladding concentricity error
- 2.3. numerical aperture differences

What are the specifications for these parameters? Table 2 provides a summary of some of the dimensional and optical specifications for OM4 multimode fiber

What is the intrinsic coupling loss when joining two fibers that are at the maximum and minimum limits of the TIA-492AAAD specification? The intrinsic coupling loss due to core diameter mismatch, core/cladding concentricity error and numerical aperture mismatch is shown in Figure 1, 2 and 3⁴ respectively.

As you can see from Figures 1, 2 and 3, the worst case fiber mismatch losses can be quite significant compared to the loss budgets allocated for 10 Gigabit and higher data rate applications. So what is happening? Typically we don't observe such high losses when testing fibers in the field. There are two reasons for this: 1) most fibers today are manufactured to tighter tolerances than these specifications and 2) not all modes are equally excited, i.e., there is less power for the higher order modes than the lower order modes depending on the mode filtering that is used (this is explained later in this paper).

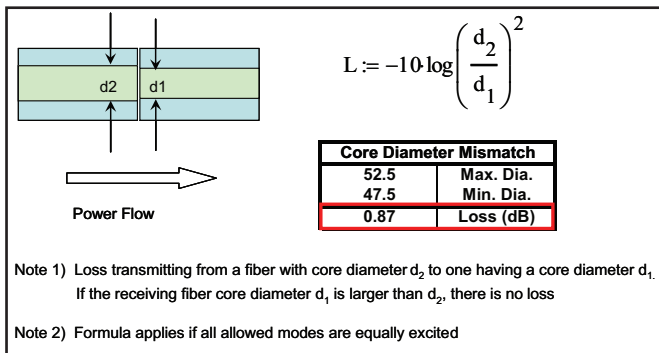


Figure 1 – Optical Loss due to core diameter mismatch

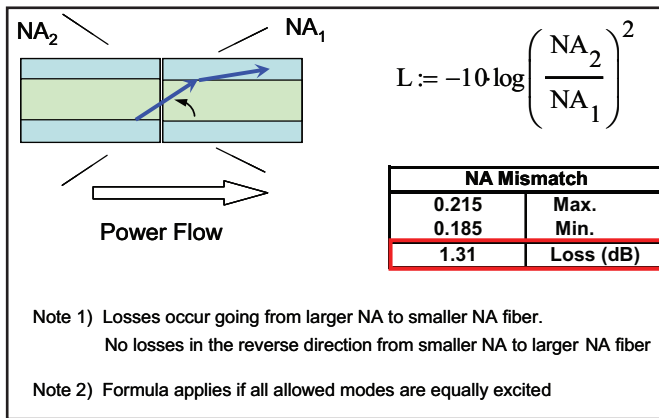


Figure 2 - Optical Loss due to numerical aperture difference

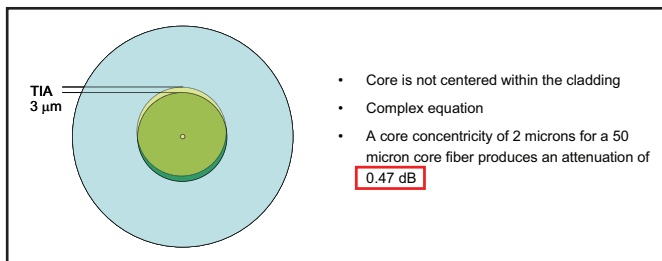


Figure 3 - Optical Loss due to core/cladding concentricity error

3. The characteristics of light source and how light is coupled into the fiber

The launch conditions and how light is coupled into the fiber can have the greatest effect on optical loss measurements. For

multimode fiber, different distributions of launch power (launch conditions) can result in different attenuation measurements. The distribution of power among the modes of the fiber is accomplished by controlling the launch spot size and angular distribution

through an optical system that couples the light into the fiber, as shown in Figure 4¹.

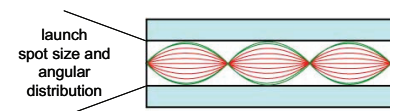


Figure 4 – Launch conditions

In graded index fiber, the lower index of refraction of the core as one approaches the cladding causes the higher order modes to follow a curved path that is longer than the axial ray (the “zero order mode”). Because the higher order modes travel farther in the glass core and have a greater likelihood of being scattered or absorbed, they have greater attenuation than the lower order modes. Therefore, a long length of fiber that was fully filled (all modes launched into the fiber at the same power level) will have a lower amount of power in the higher order modes than will a short length of the same fiber. The term “equilibrium modal distribution” (EMD) is used to describe the modal distribution in a long fiber which has lost the higher order modes. This change in “modal distribution” between long and short fibers can make big differences in the measurements one makes with the fiber. The relative mode power distribution for multimode fiber is illustrated in Figure 5¹.

Figure 5 illustrates the equilibrium mode distribution (EMD) for a long length of multimode fiber as well as the mode power distribution for a short length of multimode fiber when using a mode filter. Mode filtering strips off the higher order modes, but provides only a crude approximation of EMD.

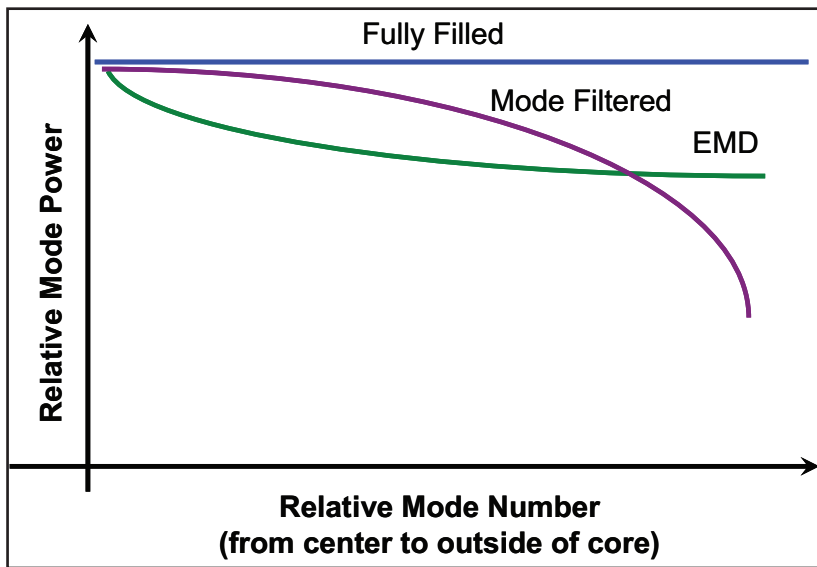


Figure 5 - Relative mode power distribution for multimode fiber

4. Mode conditioning filter

4.1. Mode conditioning filter - mandrel wrap

A launch cord that is wrapped around a mandrel is commonly used as a mode filter. A mandrel wrap stresses the fiber and increases loss for the higher order modes when launching light into the fiber under test.

The use of a mandrel wrap as a mode filter is described in Annex A.1.3.1.2 of TIA-455-78B Standard. A far field measurement is used to compare the power distribution exiting a long length of test fiber (greater than 1 km) that has been excited with a uniformly overfilling light source with the power distribution exiting a short length of the fiber with the mandrel applied. The mandrel diameter is selected to produce a far-field distribution in the short length that approximates the long length far-field power distribution.

The mandrel wrap test method is commonly used for optical loss testing in the field. The method prescribes the use of an overfilled, Category 1, light source and a test reference cord that is wrapped around a mandrel. The specification for a

Category 1 light source is determined using the Coupled Power Ratio (CPR) test as illustrated in Figure 6¹ &². Acceptable mandrel diameters for common multimode cable types (five wraps) are provided in Clause 6.4.2.1 of ANSI/TIA-568-C.0 standard.

The problem with the mandrel wrap test method is that it can result in large measurement variability. The measurement variability is due to 1) differences in the mode power distribution of the coupled light source for different test equipment since the Category 1 specification is quite broad** and 2) differences in the characteristics of multimode fibers that are used for the test reference cords since the effect of bending can vary depending on the manufacturer of the multimode fiber.

** Note: A difference of 4 dB in CPR for a Category 1 light source represents 150% increase in mode power for higher order modes

4.2. Mode conditioning filter - Encircled Flux

Encircled flux (EF) is a new method of controlling the power distribution of light that is launched from the end of a test reference cord (TRC) when performing optical loss measurements. The lower and upper boundaries of the light power distribution are specified as a function of the core radius and for each wavelength at 850 nm and 1300 nm as shown in Figure 7 [3]. EF was developed by optical experts to

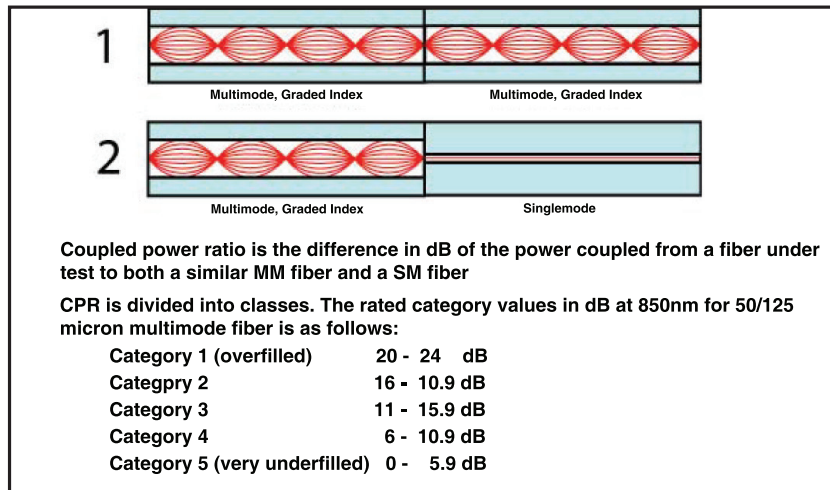


Figure 6 - Coupled Power Ratio (CPR) specification

reduce variability in link-loss measurements compared to other optical loss test methods that use an overfilled launch light source and mode conditioning filters (e.g., mandrel wrap). Encircled Flux is also the test method that is specified in the IEEE 802.3ba Standard for 40 Gb/s Ethernet (40GBASE-SR4) and 100 Gb/s Ethernet (100GBASE-SR10).

TIA Adopts Encircled Flux in New Fiber-test Standard

The Encircled Flux test method is specified in TIA TIA-526-14-B, "Optical Power Loss Measurements of Installed Multimode Fiber Cable" and is harmonized with IEC 61280-1-4 standard. TIA is currently working on a new Addendum 2 of ANSI/TIA-568-C.0 that addresses different optical fiber topics. In one section of this addendum the mandrel wrap test method as specified in TIA-455-78B and TIA-526-14-A is replaced with the following:

For multimode cabling, cabling standards describe that attenuation measurements are taken according to TIA-526-14-B. TIA-526-14-B requires that the output of the launch cord meet specific launch conditions governed by spectral width and mode power distribution. These launch conditions can be achieved either within the field-test instrument by the manufacturer, or by use of an external mode conditioner.

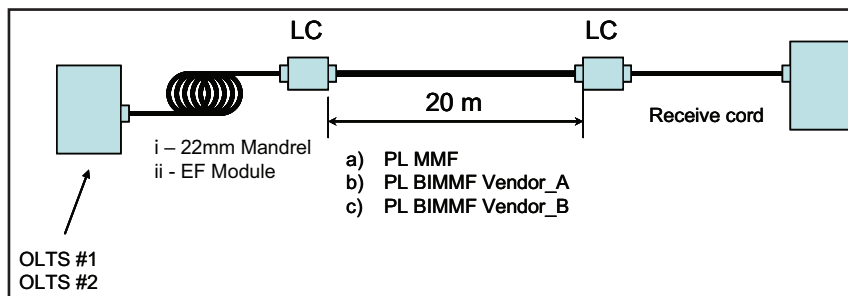


Figure 8 - Optical loss test setup using overfilled launch (OFL) with mandrel wrap versus encircled flux (EF) launch conditions

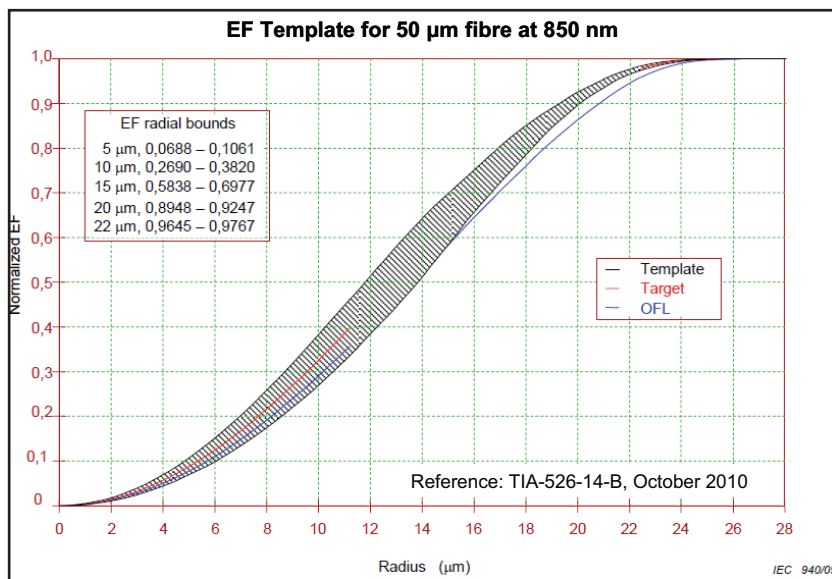


Figure 7 - Encircled flux normalized power distribution

Comparative Optical Loss Measurements Using OFL/ Mandrel Wrap per TIA-426-14-A, Method B Versus Encircled Flux TIA-426-14-B, Annex A

In order to better understand the variability in optical loss measurements, we designed a controlled experiment where we kept all the variables constant except for the launch conditions. In a first series of tests, the same permanent links PL a), PL b), and PL c), were tested with the same test reference cords

(using regular MMF), TRC #1 and TRC #2, wrapped around a 22 mm mandrel, using two different test sets OLTS #1 and OLTS #2. In a second series of tests, we substituted the test reference cords with cords that contain a built-in EF module, EF module #1 and EF module #2, in place of the mandrel wrap. The optical loss was measured under the different launch conditions described above on three, 20 meter, 2-conductor, permanent links as follows:

Permanent Link a) using regular multimode fiber

Permanent Link b) using bend-insensitive multimode fiber from vendor A

Permanent Link c) using bend-insensitive multimode fiber from vendor B

The test setup is shown in Figure 8.

Measured Results

The results of the controlled experiment are presented in Figure 9. The first series of tests were performed under the same conditions using overfilled launch light source and a mandrel wrap mode conditioning filter. There is a difference of about 0.5 dB in the optical loss when tested using OLTS #1 versus OLTS #2 for all permanent links independent of the type of fiber. What is the reason for this discrepancy?

The difference in loss measurements can be attributed to how much light is coupled into the multimode fiber for the two test instruments. Although both light sources are specified as Category 1, the specifications are not sufficient to ensure that a consistent mode power distribution is launched from the end of a reference test cord when using a mandrel wrap mode filter. A difference of 0.5 dB in loss measurements can mean a difference between a Passing link and a Failing link when working with loss budgets that are as small as 1.5 dB to 2.6 dB.

In the second series of tests, the optical loss measurements are in good agreement (within +/- 0.1 dB) for both test instruments (OLTS #1 and OLTS #2) when using encircled flux mode conditioning filter.

Some Good News!

The good news is that there is general agreement in the industry on a test procedure that can be relied on for accurate and repeatable optical loss measurements. The Encircled Flux test method reduces loss measurement variation to a goal of +/- 10% for link attenuation measurements greater than 1dB. EF compliance can be achieved through the use of a modal controller device that is either integrated into the test equipment or an external device that is inserted between the light source and the fiber under test.

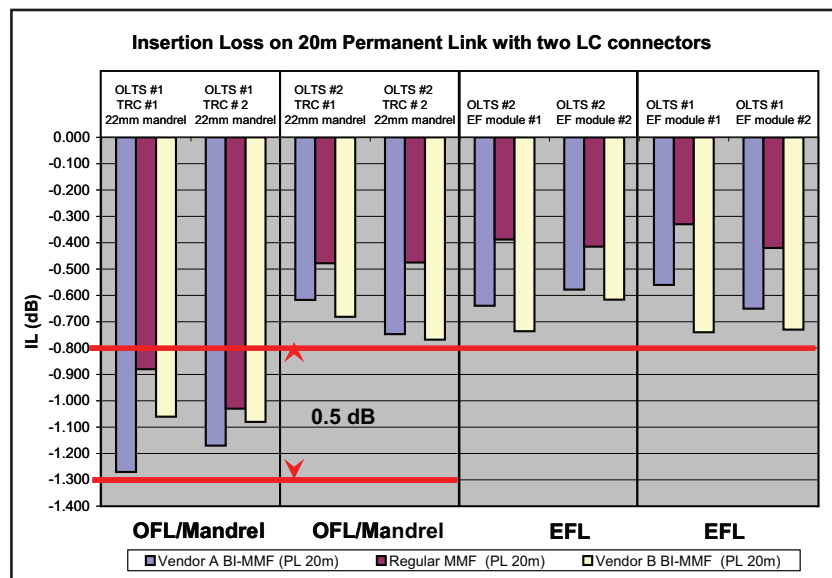


Figure 9 - Insertion loss of 20 meter Permanent Links a), b) and c) tested using two different test instruments OLTS #1 and OLTS #2 and using OFL/Mandrel wrap versus Encircled Flux mode filtering launch conditions

The EF modal controller device is a passive device that ensures that launch conditions meet the IEC 61280-4-1 requirements regardless of the light source that is used (LED or laser).

Summary

Optical loss testing in the field is not as simple as it seems and can be affected by many variables, including fiber mismatch, the type and quality of the test reference cords and the launch conditions (OFL/Mandrel wrap versus Encircled Flux). The more stringent optical loss requirements for high speed applications necessitate an accurate test method for testing links in the field. The Encircled Flux test method is recommended by industry experts for accurate optical loss measurements for both regular MMF and BIMMF.

Encircled Flux is also the test method specified for 40G and 100G Ethernet applications

About the Author

Paul Kish is the Director of Systems and Standards with Belden. Paul Kish is a key contributor to the development of cabling standards with TIA, ISO and IEEE and also serves on the BICSI Technical Information & Methods Committee.

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