

Fusion Splicing Today's Single Mode Fibers

Superior Essex and OFS have combined field experience and laboratory studies to investigate the realities of fusion splicing single mode fiber in today's FTTH environment. This white paper discusses the results and implications of the findings, and provides practical guidelines for network planners and designers as well as splicing contractors and technicians.

Superior Essex Inc. and OFS Copyright 2010, All Rights Reserved.



As FTTH (Fiber-to-the-Home) deployments proliferate and voice, data, and video networks converge, an increasing amount of optical fiber is being fusion spliced. Once viewed as art as much as science, fusion splicing has become much more routine due to improvements in the fiber itself and the development of highly sophisticated and automated fusion splicing equipment.

Despite the advances in fiber and fusion splicing technology, there are still many aspects of splicing of which practitioners must remain aware. Differences in fibers, equipment, environment and technique can yield different splice loss results. Understanding fusion splice process capability and splice loss measurement will ensure that network owners, designers, contractors, and technicians have realistic expectations of splice loss, especially with the new generation of bend-insensitive single mode fibers that are becoming popular.

This paper provides an overview of fusion splicing and highlights areas that users should be aware of. It discusses what to expect when performing splice loss measurements and offers guidance and rules of thumb for establishing acceptance criteria. This way, all parties with vested interest in the installation – designers, contractors, installers and owners, can be assured that the network will perform as expected.

What is Splicing?

Splicing is used to permanently join two optical fibers where no additional changes are expected to be made to those fibers at that juncture. This is in contrast to connectors, which are designed to allow quick re-configuration of fiber links.

There are two ways to splice optical fibers: mechanical and fusion. In a mechanical splice, the fibers are held together with ends touching inside some type of sleeve. Mechanical splices are typically used for semi-permanent connections, as in an emergency restoration or for testing and troubleshooting. Mechanical splices usually exhibit greater loss and reflection than fusion splices.

In fusion splicing, the two fibers are literally welded, or fused together. This makes for a strong joint that exhibits very low loss and virtually no reflection.

This paper focuses on fusion splicing, although much of what is discussed here can also be applied to mechanical splicing.

Fusion Splicers

Fusion splicing is performed with a piece of equipment called a fusion splicer. The fiber ends are prepared and cleaved, placed in alignment fixtures on the fusion splicer, and at the press of a button the fiber ends are heated with electrodes, brought together, and fused.

There are many models of fusion splicers available, varying in features and capability, and of course cost. High-end units allow users to store separate programs or recipes where factors such as splice time and temperature can be highly customized. Such units magnify and visually

display the splice, and use active core alignment to line up the fibers. Light injection technology and imaging software line up the cores so maximum light passes from one fiber to the other, ensuring minimal splice loss. Such splicing units can also provide an estimate of the splice loss.

More basic fusion splicers may employ clad alignment to line up the fibers for splicing. The fibers sit in a holder or V-groove, and are lined up “physically”, based on the outer diameter of the fiber’s cladding. These splicing units are at the mercy of the fibers’ glass geometry characteristics and tolerances (Clad Diameter, Clad Non-Circularity, and Core-to-Clad Concentricity). Just because the outer diameters are aligned, doesn’t mean the cores will be perfectly aligned. Such units typically produce higher loss splices and lack the features and flexibility of higher end splicers.

Fusion Splice Process Capability

The fiber parameters that most affect splice loss in single mode fiber are Mode Field Diameter (MFD – the diameter of the light-carrying region of the fiber) and Core-Clad Concentricity.

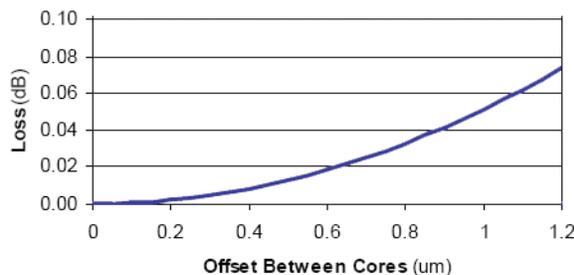
Estimated loss from mismatches in MFD can be calculated from the following equation:

$$\text{Loss (dB)} = 20 \times \text{LOG}_{10} [(2 \times \text{MFD}_1 \times \text{MFD}_2) / (\text{MFD}_1^2 + \text{MFD}_2^2)]$$

Today’s typical MFD specification for type G.652 single mode fiber is $9.2 \pm 0.4 \mu\text{m}$ at 1310 nm. Even at the opposite extremes of this spec, losses due to MFD mismatch should be $\leq 0.033 \text{ dB}$ (Note that the ITU-T G.652 spec actually allows a deviation in MFD of 7.9 to $10.2 \mu\text{m}$, resulting in a potential splice loss of 0.3 dB.) If unlike fibers with differing MFD’s are spliced, for example G.655 NZDF, or the new generation of G.657 bend insensitive fibers, the splice losses will likely be higher than when splicing like fibers. However, even these cases should be manageable with proper system design and practical splice specifications.

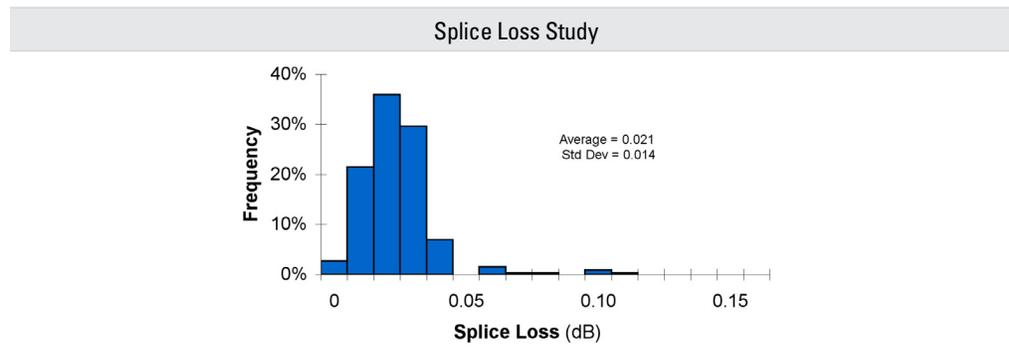
Core-Clad Concentricity Error, or the amount that the core is off-center from the cladding, can also contribute significantly to splice loss in single mode fiber. The following graph shows how much loss there could be for a given amount of offset between the cores of spliced fibers.

Relationship Between Splice Loss and Offset Between Cores



The typical specification for Core-Clad Concentricity in today’s G.652 single mode fibers is $\leq 0.5 \mu\text{m}$. If two fibers, each with this much core offset, are spliced such that the offset is in opposite directions (total $1 \mu\text{m}$ offset), 0.056 dB loss could be expected.

Between MFD mismatch and core offset, maximum potential splice loss should be ≤ 0.089 ($0.033 + 0.056$) dB. However, this only represents intrinsic loss due to fiber geometry and does not account for any additional loss introduced by the splice equipment, operator, or the environment. It may be rare that the extremes of each spec are encountered in the field, but a recent splice study performed by OFS on G.652 single mode fiber (OFS to OFS, and OFS to competitor) did yield some splices that had losses of 0.1 dB or higher. Average splice loss of all samples was quite low at 0.02 dB, but there were instances where losses exceeded 0.1 dB.



As the graph shows, the vast majority of splices were below 0.05 dB, but there were several above that, as well as a few above 0.10 dB.

It should also be noted that splice studies performed in a lab, like those referenced here, are usually done in ideal and relaxed conditions with state-of-the-art, well-maintained splicing equipment and cleavers. In reality, splicing is often done in haste, and in less than ideal conditions (cold, windy, dusty/dirty...) with equipment that may be well used and not performing at its very best. Losses even greater than those seen in the splice studies here can be expected in field conditions.

Measuring Splice Loss

Once a splice has been made, it often needs to be measured to see how much loss occurs at that joint. There are several techniques and approaches to doing this. Which method, or combination of methods, is used will depend on various factors, including the design, purpose, and critical nature of the network, as well as any industry specifications or standards that may govern such.

There are three basic ways to obtain a splice loss reading. The three methods are detailed here, along with their advantages and limitations.

Fusion Splicer Estimated Loss

Immediately after completing a splice, many fusion splicers display an estimate of the splice loss. This can give you a quick indication of the general quality of the splice, but it is exactly that – an estimate. Caution and prudence is urged in relying on estimated splice loss to determine whether a splice is acceptable. There are no standards governing splice loss measurements by a fusion splicer, and no means of calibration, so the accuracy of such measurements can vary widely.

A fusion splicer's estimated splice loss reading is most often used to determine whether or not to immediately remake a splice. If the reading is high, an immediate remake may be prudent. Where to set this re-splice criterion depends on the splicer, the fibers, the technician, and environmental factors (temperature & humidity, wind, dust, etc.). The most thorough method is to perform a splicing trial where a dozen or more splices are performed and measured by other means (as indicated below) and compared to the splicer's estimated readings. This provides a correlation between the splicer's estimate and the actual results. This trial may need to be repeated periodically, especially if there's a change in fiber type/manufacturer, technician, or environment. If such a trial is not prudent, the remake criterion should at a minimum be set at the mean splice loss specification for the job. Setting it any lower will likely result in rework without really knowing if the rework is necessary.

OLTS (Optical Loss Test Set, also known as a Source and Power Meter)

A traditional source and power meter can be used to estimate splice loss on a relatively short link containing one splice. This is still somewhat of an estimate, since an OLTS measures the loss over the entire link, which would include the fiber as well as the splice. In a relatively short link, the loss due to just the fiber itself should be quite small, so the power meter reading would be close to, or just slightly higher than, the actual loss of the splice. If the attenuation of the cable is known, it can be subtracted from the power meter reading to get a closer estimate of the splice loss.

On longer links, more of the overall loss will be attributed to the fiber itself, making it more difficult and less accurate to estimate the loss of a splice. Also, keep in mind that if there are multiple splices in a link, an OLTS will only report the total loss of all the splices. It cannot distinguish between individual splices. Only the average loss of each splice can be determined.

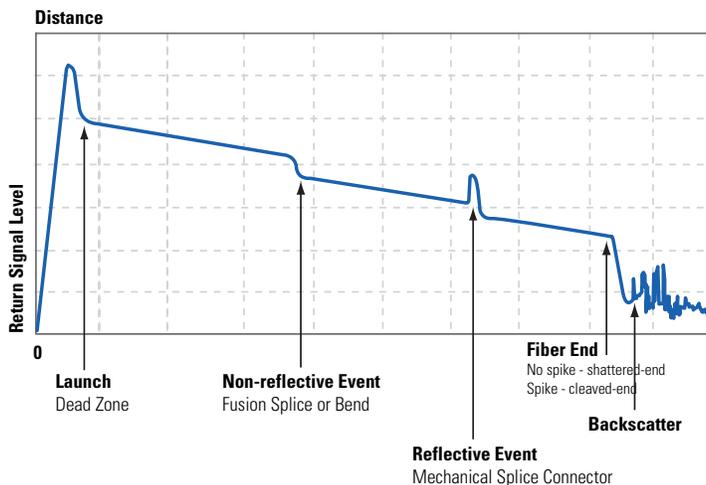
OLTS's are an economical and useful way to make sure a link meets a power budget requirement, which of course is the number one criterion. Even if there are splices in a link that might be considered "high" (high splice loss), it does not matter as long as the overall link meets the link loss requirement. Splices won't get worse over time (assuming it was fused properly) and link budgets usually have a safety factor built in for environmental and aging considerations, so a high loss splice in a link that meets its loss budget should not be of concern.

OTDR (Optical Time Domain Reflectometer)

An OTDR is a specialized test instrument for optical fiber. It is a very useful tool in that it provides a representative picture of the fiber and only requires access to one end of the fiber. An OTDR is the only means of obtaining a truly accurate splice loss measurement. Still, a good understanding of how an OTDR works – and its limitations – is necessary in order to avoid confusion or debate in determining whether splice loss requirements are met, and to prevent any unnecessary rework or delay.

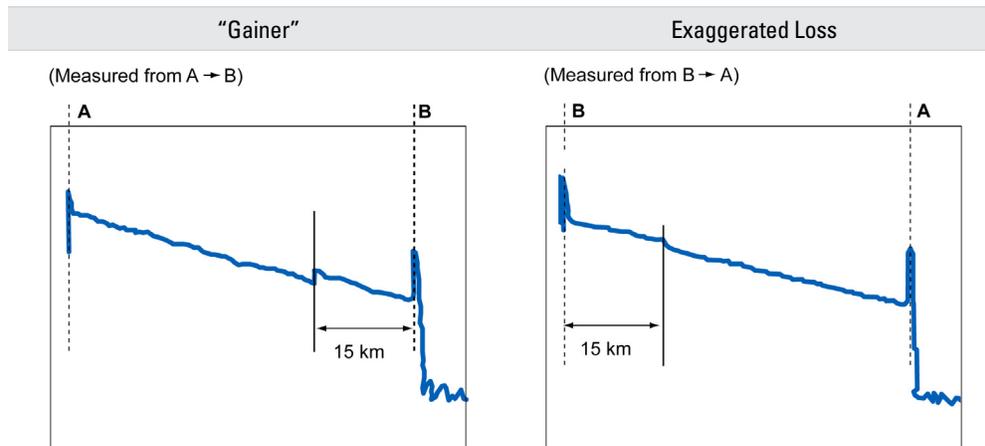
An OTDR uses back-scattered, or reflected, light to measure loss over distance. The OTDR shoots pulses of light into the fiber and measures how much light is reflected back and how long it takes to travel back. It displays the measurements in a graph known as a trace which is simply signal power versus distance. The trace displays how much loss there is anywhere along the length of a fiber, or along a link that includes connections and splices.

Typical OTDR Trace



Since an OTDR measures reflected light, it is actually an indirect measurement and is therefore only an estimate of the power loss in a fiber. A direct measurement method, such as the OLTS described above, is more accurate for total end-to-end loss measurement, but does not provide the picture and single-end testing.

Also because an OTDR measures reflected light to determine loss, it can sometimes be “fooled” into thinking that there is more or less loss than there actually is. The reason is that the amount of light reflected back is affected by changes in MFD. If light goes from a smaller MFD into a larger MFD, less light is reflected back, making it seem like the loss is greater than it really is. Conversely, if light goes from a larger MFD into a smaller MFD, more light is reflected back at this point and the OTDR will think that power was actually gained at the splice (often called a “gainer”). In reality, power cannot be gained, and some amount of loss occurs at the splice joint. However, remember that even with two fibers at the opposite extremes of the typical MFD spec, actual loss due to MFD mismatch will be ≤ 0.033 dB.



Mode field mismatch often happens when fibers from different manufacturers, or different types of fibers, are spliced together. This is due to differences in MFD among fiber types and manufacturers. However, mode field mismatch can also occur when splicing the same fiber type from the same manufacturer. This can happen simply due to the manufacturing tolerances of the fiber. World class fiber manufacturers have narrowed the tolerance for MFD to $\pm 0.4\mu\text{m}$ at 1310nm and $\pm 0.8\mu\text{m}$ at 1550nm. However, even these microscopic differences will show up on an OTDR if one fiber is on the upper side of the tolerance and the other is on the lower.

The important point to remember is that the gainer is "apparent" and the loss is "exaggerated". So how do we determine the correct splice loss?

Importance of Bidirectional Measurement

The industry recognizes that the most accurate measurement of actual splice loss is the average of a 2-way (bidirectional) test. This is documented in industry standard ANSI/TIA/EIA-455-8-2000 Measurement of Splice or Connector Loss and Reflectance using an OTDR.

Splice Loss = Average of measurements from both directions

Example 1	
Measurement 1 – CO to Field – Splice loss:	0.18 dB
Measurement 2 – Field to CO – Splice loss:	-0.14 dB (Gainer)
Sum:	0.04 dB
True Splice Loss Average:	0.02 dB – bidirectional average

Example 2	
Measurement 1 – CO to Field – Splice loss:	-0.20 dB (Gainer)
Measurement 2 – Field to CO – Splice loss:	0.14 dB
Sum:	-0.06 dB
True Splice Loss Average:	-0.03 dB* – bidirectional average

Example 3	
Measurement 1 – CO to Field – Splice loss:	0.10 dB
Measurement 2 – Field to CO – Splice loss:	0.00 dB
Sum:	0.10 dB
True Splice Loss Average:	0.05 dB – bidirectional average

*Note: Even though the “true splice loss” is negative in this case, as we have already stated, power cannot be gained through a splice. However, due to the OTDR’s margin of error, negative bidirectional averages are possible. In reality, the loss in such a case is likely negligible.

1-Way vs. 2-Way OTDR Measurements

Because of an OTDR’s inherent benefit – the ability to measure a fiber optic link from one direction – there is a temptation to only do 1-way (unidirectional) measurements to certify a link, including splice losses. However, if certification is required, measurements should always be taken from both ends and results averaged (many OTDRs do the averaging for you). Even if certification is not explicitly required, true performance can only be verified by taking bidirectional readings.

It does no good, and serves no purpose, to perform (or even require) certification from one direction only. Unidirectional results do not reflect the true performance of a splice, and in fact can mislead someone into thinking the splice is OK, or not OK, when the opposite is actually true. Imposing unidirectional specs will only lead to extra work and heartache.

Unidirectional OTDR measurements are useful for troubleshooting, or for 1st-pass assessment of splices in order to decide if any should be remade before going to the other end of the link to take measurements from the other direction. As long as a reasonable and moderate limit is put in place on unidirectional loss (see section on Splice Loss Specifications), this can save time. The few splices that might read high can be remade. But the majority that read fine or even “a little high” will in all likelihood be fine when measured at the other end and bidirectional results are averaged.

Splice Loss Specifications

Splice loss specs are intended to ensure that the overall link loss is within budget. System performance is dependent on overall link loss, not individual splices. For example, if the loss budget on a link is 8 dB (after safety margin), and the attenuation in the cable only contributes 4.8 dB (e.g. 0.4 dB/km over a link of 12 kms is 4.8 dB), then 3.2 dB is available for total splice loss. Typically, some splices will be on the higher side, but these will be offset by splices on the lower side. As long as they all add up to no more than 3.2 dB, there won’t be a problem.

Imposing a stringent splice loss spec on all splices in a link may be counter-productive. In general, a reasonable splice loss spec should be established based on the design of the link and should be an average of all splices. Is there a stringent power budget? Then perhaps the splice loss spec should be ≤ 0.1 dB average. Is there plenty of power budget? Then a spec of ≤ 0.25 dB average might be completely sufficient. If individual splice loss limits are imposed, keep in mind that due to fiber geometry variation, equipment, environmental conditions, technician expertise, etc., some individual splices may not meet the spec no matter what. There should be some allowance for such. One splice that may not quite meet the spec will certainly be offset by several other splices that are well within the spec.

Avoid setting a unidirectional splice loss specification. Unidirectional measurements are only useful as guidance and have no real bearing on the actual performance of the splice. If unidirectional measurements are used at all, it should be done with some knowledge of the fiber being spliced, along with the capability of the equipment being used. If a unidirectional limit is too tight, it will cause many unnecessary remakes.

One strategy that can be useful in the field is to set a unidirectional threshold of 0.3 dB or higher, which would trigger a remake. If after two tries, the one-way measurement does not come down, a mode-field mismatch is very likely. The splice should be measured from the other direction to determine its true loss before spending more time on remakes.

Guidelines for Network Planners and Designers

Industry specifications vary somewhat in the allowable loss for splices, but agree on two major points:

- Splice loss is based on a bidirectional average OTDR measurement
- Splice loss specification is based on the mean splice loss of all splices.

To ensure the end result of a high-performance network at the lowest installed cost, Network planners and designers should:

- Set splice loss specifications based on the overall requirements of the link
- Set splice loss specifications based on the mean splice loss of all splices
- Specify bidirectional average OTDR measurement for splice loss measurement
- Avoid specifying unidirectional OTDR splice loss requirements

Guidelines for Splicing Contractors and Technicians

Many advances have been made in optical fiber and the equipment used to splice it, but fusion splicing remains a technical skill that can be affected by many different factors. To ensure quality, efficient fusion splices with minimal rework, splicing contractors and technicians should consider the following guidelines:

In General

- Follow the applicable equipment manufacturer’s guidelines for setup and maintenance of all splice equipment.
- Maintain clean equipment and a clean splice environment, being especially wary of windy and/or dusty conditions.

Splice Loss:

- Use the fusion splicer’s estimated splice loss reading as an initial go/no-go evaluation of the splice.
 - » Establish the limit at the same dB value as the mean splice loss value in the job specification.
 - » If the initial splice does not fall within the limit, repeat the splice no more than two more times without performing a bidirectional OTDR average to validate the finding.
- If using unidirectional OTDR testing to qualify splices:
 - » Do not break and re-splice gainers. They typically will not change significantly.
 - » Set a generous threshold for remake.
 - » Do not break and remake excessive losses more than once without performing a bidirectional OTDR average to validate the finding.

Conclusion

Fusion splice loss is affected by many factors, some of which can be controlled or manipulated by splice technicians and some of which cannot. Variations in glass geometry (MFD, core-clad concentricity) between fiber types, fiber manufacturers, and even within the tolerances of the same fiber type, can result in true splice losses exceeding 0.1 dB, and unidirectional measurements (gainers, or exaggerated losers) even higher.

An OTDR is the best device to use for measuring splice loss, with the true loss being the average of bidirectional measurements. Unidirectional measurements can be misleading, sometimes showing a gain in power (“gainers”) or exaggerated loss. This is due to natural variations in MFD between spliced fibers and the way the OTDR measures the backscattered light at these joints.

With the increasing amount of optical fiber being fusion spliced in today’s broadband and access networks, it is important to have a good understanding of the factors that affect splice loss, as well as the various measurement aspects surrounding splice loss verification. Splice loss specifications should be set with the total link power budget in mind and be based on average splice loss. This will ensure that an installation has realistic splice loss requirements and that the power budget can be met with confidence while minimizing the time and expense associated with splice remakes.

Company	Representative	Contact Info
Superior Essex 6120 Powers Ferry Road, Suite 150 Atlanta, GA 30339	Tim West, RCDD Director of Engineering Services Communications Division	770-657-6000 tim.west@spsx.com
OFS 50 Hall Road Sturbridge, MA 01566	Tony Irujo Manager Customer Tech Support Optical Fiber Division	508-347-8590 tirujo@ofsoptics.com