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Applications
Engineering Note

Uni-directional Single-mode OTDR Measurements

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OTDR Operation

Optical Time Domain Reflectometers (OTDR) are widely used with telecommunications products and systems for testing bare and cabled fiber, as well as performing final system acceptance testing. OTDRs can measure the attenuation coefficient of fiber, be used to analyze discreet events in a link such as splice points or connector pairs, and can also locate damaged or distressed cable or broken fibers.

OTDRs operate by measuring the amount of light scattered back to a source by the fiber itself. It is generally accepted that for telecommunications grade fiber the percentage of backscattered light is constant along the length of a given fiber. The term representing the percentage of backscattered light is called the backscatter coefficient. The backscatter coefficient is negative by convention and is typically expressed in units of decibels (dB). Different fibers, however, can have different backscatter coefficients. If significant, such differences can lead to a misinterpretation of OTDR results.

If the backscatter coefficients of fibers located immediately before and after a splice point are significantly different, the OTDR trace can display either an apparent gain or an exaggerated loss in optical power. These unidirectional OTDR trace anomalies are most common at a junction consisting of fibers from different manufacturers and/or of dissimilar fiber types (a.k.a., hybrid splices). They can, however, also occur in systems of a homogenous fiber type.

Interpretation of Splice Results

If the amount of light being backscattered from a fiber on the launch side of a splice is lower than from the fiber on the other side of the splice, the OTDR may interpret this difference as an apparent increase in power. In this case, the fiber preceding the splice (i.e., on the side of the OTDR) has a higher negative higher backscatter coefficient than the fiber located after the splice. If the apparent increase in power is greater than the loss in power due to the splice itself, the OTDR trace shows this as a "gainer" or an overall increase in optical power. Measured in the opposite direction, the OTDR trace for the same splice junction would show an exaggerated, or excessive, loss. In this case, the loss displayed by the OTDR is a combination of the actual splice loss as well as apparent loss resulting from the different backscatter coefficients.

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Note that the amount of "gain" displayed by the OTDR in one direction is equal, but opposite to, the amount of excess loss seen in the opposite direction. By performing a bi-directional measurement and averaging the results the effects due to backscatter differences can be cancelled out. Industry test procedure EIA/TIA FOTP-61, "Measurement of Fiber or Cable Attenuation Using an OTDR," states that OTDR measurements of single-mode fiber splice loss must be taken in both directions if an accurate splice loss measurement is to be made. However, in order to save on installation costs, some customers may continue to employ uni-directional OTDR splice loss measurements.

These OTDR display anomalies, resulting from the machine's interpretation of the different backscatter coefficients of the two fibers, is the byproduct of an assumption used in the logic that drives the OTDR display. The assumption is that the entire length of fiber under test has a constant backscatter coefficient. In homogenous systems, this assumption is valid; however, real-world applications and economics sometimes result in the use of dissimilar fibers in the same system.

The backscatter coefficient for optical fiber is related to the mode field diameter (MFD), which is specified for all single-mode fiber types. The splice loss measured by the OTDR is thus shown by the equation:

$$\text{OTDR LOSS} = \text{ACTUAL SPLICE LOSS} + 10 \log_{10} \frac{\text{MFD [after the splice]}}{\text{MFD [before the splice]}}$$

Written another way:

$$\text{ACTUAL SPLICE LOSS} = \text{OTDR LOSS} - 10 \log_{10} \frac{\text{MFD [after the splice]}}{\text{MFD [before the splice]}}$$

[NOTE: Additional error may be incurred due to differences between specific OTDR units.]

Unidirectional Splice Loss Thumbrule

When two different fiber types with differing nominal MFDs are spliced together, the effect on the splice loss as measured with an OTDR can be estimated by the following relationship:

$$\alpha_{sl} = \left| 10 \log_{10} \frac{\text{MFD [Fiber 1]}}{\text{MFD [Fiber 2]}} \right|$$

where α_{sl} is the apparent loss or gain resulting from mismatched MFD values.

This is a good rule-of-thumb to mitigate the risk associated with performing uni-directional OTDR splice loss measurements on hybrid splices. The resulting value can be added or subtracted as appropriate to the measured splice loss to get an estimate of the actual splice loss. A specific example is included below.

> When the OTDR is measuring <u>from a higher</u> MFD fiber <u>to a lower</u> MFD fiber, <u>add</u> the equation result to the <u>measured</u> splice loss to compensate the for apparent gain.
>
> When the OTDR is measuring <u>from a lower</u> MFD fiber <u>to a higher</u> MFD fiber, <u>subtract</u> the equation result from the measured splice loss to compensate for the exaggerated loss.

Example

Estimated splice loss between different dispersion un-shifted single-mode fibers with MFDs of 9.3 and 8.8 at 1310 nm. The contribution to measured splice loss from the differing MFDs is:

$$\alpha_{sl} = \left| 10 \log_{10} \frac{\text{MFD [9.3]}}{\text{MFD [8.8]}} \right| = 0.24 \text{ dB}$$

The corrections used to estimate true splice loss from unidirectional OTDR measurements are:

> When measuring from the 9.3 µm MFD (Corning Inc.) fiber to the 8.8 µm MFD fiber, <u>add 0.24 dB</u> to the measured splice loss to compensate for the apparent gain.
>
> When measuring from the 8.8 µm MFD fiber to the 9.3 µm MFD (Corning Inc.) fiber, <u>subtract 0.24 dB</u> from the measured splice loss to compensate for the exaggerated loss.

Note: It is important to remember that splice loss is reported as a positive number.

Statistical Analysis of Thumbrule

A Monte Carlo analysis was performed to evaluate the validity of the thumbrule when used with uni-directional splice loss measurements. Measurements performed on hybrid splices and like-fiber splices were compared to actual loss measurement results. A summary follows:

Probability That Unidirectional Measured Loss Within the Range of Actual Loss		
RANGE	Dissimilar Fibers (Thumb Rule)	Similar Fibers
± 0.05 dB	51%	54%
± 0.10 dB	75%	78%
± 0.15 dB	89%	91%
± 0.20 dB	96%	97%
± 0.25 dB	99%	99%
± 0.30 dB	99.6%	99.8%

Therefore, it can be shown that by using the thumb rule discussed above estimates of the actual splice loss of hybrid splices can be made to within a good approximation. Testing shows that these thumb rules work for both 1310 and 1550 nm splice loss measurement estimates.

NOTE: Accurate splice loss values can only be achieved by one of the following methods

- Power-through measurement.
- Bi-directional OTDR measurement
- LID-SYSTEM® unit on a Corning Cable Systems fusion splicer or OptiTest™ unit

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Corning Cable Systems recommends one of these methods when evaluating splice loss. For further information, see Corning Cable Systems Applications Notes: Remake Rules for Splicing Single-mode Fiber "Gainers."

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