Engineering Services Department
800 17th St NW | PO Box 489
Hickory, North Carolina 28603-0489

800 743-2671
f 828 901-5533
www.corning.com/opcomm

Applications
Engineering Note

Multimode Gainers

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James Joule proved that energy can neither be created nor destroyed - it only can be changed from one form to another. However, the OTDR trace displayed in Figure 1 shows an apparent increase in pulse power across a multimode fiber splice junction. The phenomenon is also known as a “gainer.”

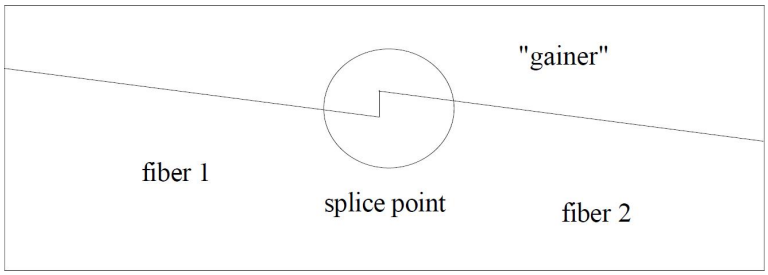

Figure 1: OTDR Trace; Displayed "Gainer"

The increase in the displayed power level leads to the erroneous assumption that power has been created through this splice. To explain this “gainer” effect, a closer look has to be taken at the principles of operation of an OTDR in measuring attenuation.

Fiber attenuation has three main components: scattering, absorption, and loss of guidance. Scattering is the loss of energy due to imperfections in the glass and from the interactions of photons and silica at the atomic level. Absorption is the process by which impurities in the fiber absorb optical energy. Loss of guidance occurs when light is radiated away from the core and is lost through the cladding. Such loss typically results from microbending or macrobending of the optical fiber due to improper handling or installation.

In order to determine fiber attenuation, OTDRs measure the portion of the scattered light that is transmitted back down the fiber toward the original launch point. This is referred to as “backscattered” light, and it is assumed to be proportional to the intensity of the initial light pulse as it travels down the entire length of the fiber.

Even though this assumption works well for a homogenous length of fiber, there are cases in which it
no longer holds true. Figure 2 shows two different fibers spliced together which have the same nominal attenuation performance, but with different distributions among the major loss components (i.e., scattering, absorption, and loss of guidance).

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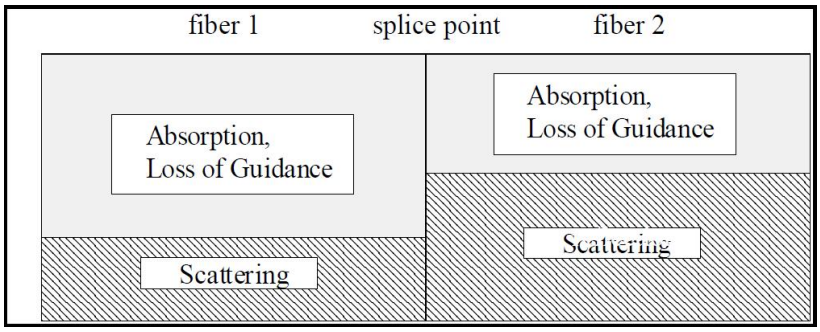

Figure 2: Distribution of attenuation components of an optical fiber

The higher scattering coefficient of fiber 2 means a higher percentage of the light pulse will be backscattered to the OTDR. The OTDR, seeing the increase in backscattered light energy, interprets it as an increase in the power level of the original pulse as it transitions across the splice, resulting in a “gainer” on the OTDR display.

When the fiber splice is tested from the opposite direction, the gainer will turn into an exaggerated loss, as the level of backscattered light to the OTDR makes an instantaneous drop. See Figure 3 below.

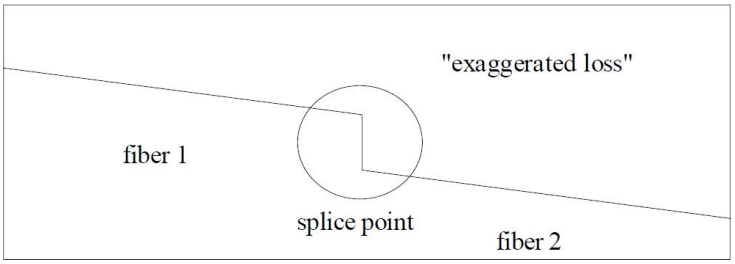

Figure 3: OTDR Trace:; Exaggerated Loss

The proper way to account for a difference in the backscattering coefficient across two fibers is to perform a bi-directional attenuation average. By measuring the attenuation from both directions, and then taking the average, the "gainer" and the "exaggerated loss" will cancel each other out, leaving only actual loss.

Care has to be taken when multimode fibers with different diameters are spliced together. In the case of Figure 3, a truly directional loss may exist which is not due to the OTDR’s measurement method (see Applications Note "Multimode Splice Loss"). The Electronics Industries Association's EIA/TIA-455-61, "Measurement of Fiber or Cable Attenuation Using an OTDR," states that OTDR measurements should be performed from both directions.

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Dealing with "Gainers" and "Exaggerated Losses"

When splicing in the field, the following is brief guidance how to deal with OTDR "gainers" and/ or "exaggerated losses."

1. Whenever a "gainer" is observed, a low loss splice exists; "gainers" are therefore a good indication of quality splices and should be kept.

2. If an "exaggerated" splice loss reading occurs, an OTDR measurement should be taken from the opposite direction. The following are the possible results from this second measurement.

   a. High splice loss - This would indicate a bad splice and resplicing is recommended.

   b. Average splice loss - A truly directional loss may exist. If so, resplicing will not significantly improve the splice loss (see Applications Note: "Multimode Splice Loss").

   c. Low splice loss or a "gainer" - Fibers with different backscatter coefficients might be spliced together. In this case, resplicing will not significantly improve the splice loss (see Applications Note: "Multimode Splice Loss").

In reality, an overlay between multiple factors occurs, making absolute recommendations impossible.

Mathematical Abstract

Condition for gainers:

The OTDR splice loss for a multimode fiber can be expressed as:

$$L = \frac{L_{AB} + L_{BA}}{2} + 5\log\frac{S_B}{S_A} \quad (1)$$

where: L = OTDR splice loss
L_{AB} = transmission splice loss in the forward direction
L_{BA} = transmission splice loss in the reverse direction
S_A = backscattered light in fiber A
S_B = backscattered light in fiber B

A gainer occurs if “L” is a negative value. Therefore, S_B must be smaller than S_A (the log of a number turns negative if the number is smaller than 1) and the absolute value of the second term in equation 1 must be higher than the absolute value of the first term. Mathematically:

$$\left|5\log\frac{S_B}{S_A}\right| > \left|\frac{L_{AB} + L_{BA}}{2}\right| \quad (2)$$

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Influence of parameters:

To discuss the influence of the various fiber parameters, a closer look at the value of the backscattered light (S) must be taken:

$$S = \frac{1}{2} \cdot \Delta \cdot \quad \alpha_r \cdot \frac{W}{2} \qquad (3)$$

for near parabolic graded index multimode fibers

where: α_r = backscattering coefficient
W = length of the incident pulse
Δ = relative refractive index

The only fiber dependent parameters in this equation are α and Δ. A change in either of these parameters, from one fiber to another, may result in a "gainer." Large differences between α_{r1} and α_{r2} ($\alpha_{r1} < \alpha_{r2}$) and/or Δ_1 and Δ_2 ($\Delta_1 < \Delta_2$) respectively, lead to the possibility of an OTDR displayed gainer if a low transmission splice loss exists.

Summary

A "gainer" is the result of a difference in the backscatter coefficients between two fibers on either side of a splice and limitations in the logic by which OTDRs operate. When viewed from the opposite direction, the gainer will be displayed as an exaggerated loss. However, "gainers" can be indicative of a quality splice and should usually be kept.

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