Understanding and mitigating OTDR “gainers”

app note

EXFO

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Introduction—OTDR trace "gainers"

Occasionally, while testing a passive optical circuit (with no optical amplifiers present), a fiber field technician may encounter an optical time domain reflectometer (OTDR) acquisition trace including an event with this general appearance (Figure 1):

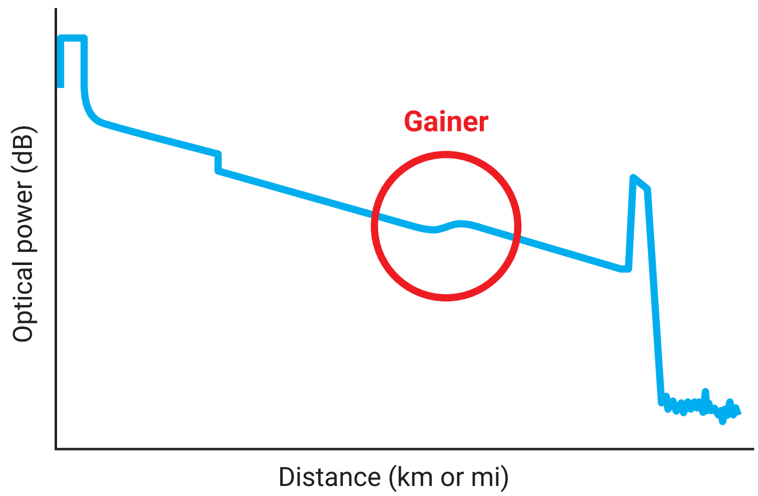

Figure 1. Gainer on simplified OTDR trace

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This localized increase in reflected optical power some distance from the launch point is fully unexpected, and can be confusing, particularly for non-expert OTDR users. Gainers are false positives that potentially lead to errors in fiber channel loss calculations and data rate impairments on high bandwidth links requiring additional truck rolls and other unnecessary operating costs to resolve. What are OTDR gainers? How are they caused? And how can they be mitigated?

OTDR operation refresher

Recall that an OTDR uses precisely timed laser pulses and a high dynamic range photodetector to measure the tiny amount of light that is backscattered (reflected back towards the OTDR by the fiber silica glass itself) to identify "events" along the link, such as fiber breaks, dirty connectors, macrobends, splices and high-loss passive elements including WDM muxes and demuxes. OTDRs are sophisticated instruments, and as such the reflected signal is subjected to algorithmic digital processing, and events are analyzed, interpreted and classified to simplify operation in the field.

The first red highlighted event in Figure 2 is a so-called "non-reflective" event that is typical of a fusion splice of two fiber ends, with no spike in the return reflection, and a low insertion loss (IL) of typically 0.1 dB or so. The overall downward slope of the OTDR trace is caused by the physics of fiber attenuation (absorption and scattering) and is typically about 0.2 dB per km at 1550 nm for a singlemode fiber cable. If the end of the cable is an optical open (an air interface to a ferrule dust cap for example), the different indices of refraction of the two materials (silica glass fiber core to air interface) cause a relatively large amount of backscatter, as shown in Figure 2. So how do we account for the physics of the gainer (which is a "negative loss") shown in Figure 1? It shows an event with an increase in optical power (like an optical amplifier) with little or no back reflection.

OTDR gainers are almost always caused by key physical differences in two spliced fibers.

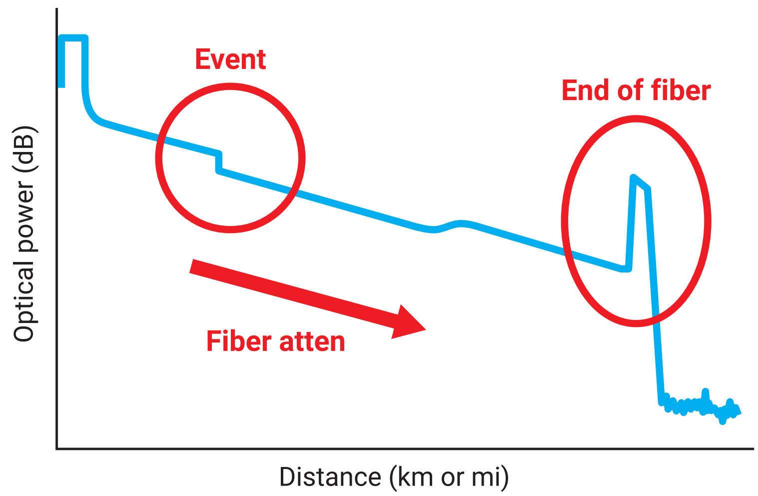

Figure 2. OTDR event examples

Fiber mode field diameter mismatch

It turns out that OTDR gainers are almost always caused by key physical differences in two spliced fibers. Different types of fiber have different core diameters: for example, singlemode fiber has a typical core diameter of 9 microns, and multimode core diameters typically have 50 or 62.5 microns. The related concept of mode field diameter (MFD) is illustrated in Figure 3.

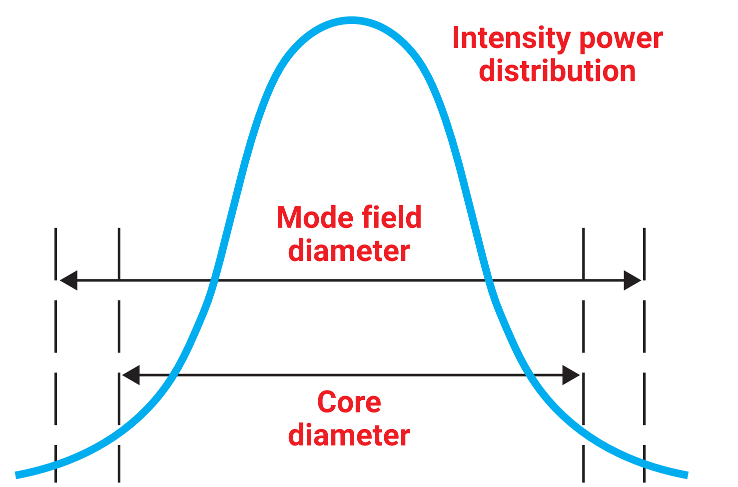

Figure 3. Mode field diameter concept

The MFD is slightly larger than the core diameter due to a physical phenomenon called the evanescent field, in which the propagating light scarcely penetrates the cladding that encases the fiber core. Interestingly, the mode field diameter varies even among similar fiber types. For example, standard G.652 SMF-28 fiber at 1550 nm has an MFD of 10.4 ± 0.5 microns, while bend insensitive G.657 SMF at 1550 nm has an MFD of 9.5 ± 0.5 microns, **a difference of nearly 1 micron** (more than 1% of the nominal core diameter). It is very common to see an OTDR gainer when standard singlemode fiber has been spliced with bend insensitive (BIF) singlemode fiber, due to their MFD mismatch (i.e., a refractive index discontinuity leading to higher Fresnel reflection). OTDR analysis algorithms are not generally "aware" of this fiber mismatch, and exaggerate the losses, as shown in Figure 4.

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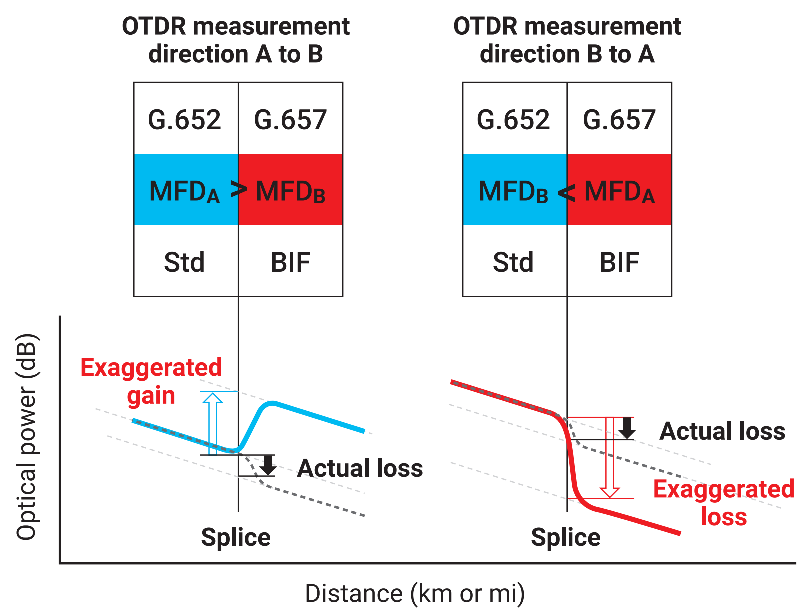

Figure 4. Exaggerated gain and loss due to MFD discontinuity (Courtesy of Corning)

To summarize, at the splice point from standard SMF to BIF SMF (direction A to B in Figure 4), there is more light reflected back to the OTDR than the case when the fiber type is homogeneous, hence the exaggerated gain (gainer) on the OTDR trace. Similarly, at the splice point from BIF SMF to standard SMF (direction B to A in Figure 4), there is less light reflected back to the OTDR than the case when the fiber type is homogeneous, hence the exaggerated loss ("loser") on the OTDR trace. Note that this second case looks to the user as a familiar splice event, albeit with a higher than actual loss, and thus can be overlooked by non-experts. Also note that gainers can occur when the launch and receiver cables used in an OTDR test setup differ (with respect to MFD) from the fiber under test, as well as when core alignment is poor during fusion splicing. Very small gainers can be caused by splicing "identical" fiber types from different manufacturers or even when using different batches of fiber from the same cable manufacturer. It is important to understand the end-to-end physical characteristics of the fiber under test when conducting Tier 2 characterization with an OTDR.

Gainer mitigation with bidirectional averaging

The best way to avoid misleading OTDR gainer results is to use bidirectional acquisition, in other words, shooting the link under test from both ends. Bidirectional OTDR measurements essentially average the two-way data to render the most accurate loss results—the backscattering ratio difference due to the MFD mismatch is reversed. For example, from Figure 4:

- Direction A to B exaggerated event loss: –0.25 dB (negative loss is a gainer)
- Direction B to A exaggerated event loss: 0.35 dB
- Average: [(–0.25 dB) + (0.35 dB)]/2 = 0.05 dB accurate event loss

The most common way to perform bidirectional fiber characterization is to perform the OTDR acquisitions from near-end (A) to far-end (B) to get "A to B" measurements, and then from far-end (B) to near-end (A) to get "B to A" measurements. This can be done either using two OTDR instruments (one on each end) or using a single OTDR that is moved to the far-end after near-end acquisitions are completed. Once all A to B and B to A measurements are done, the averaging calculations for each single fiber link is typically done by matching each A to B acquisition to its B to A counterpart acquisition in a post-processing software application. This requires paying careful attention to file naming to ensure correct matching, especially when dealing with a high volume of fiber link measurements.

EXFO's OTDRs with the iOLM (intelligent Optical Link Mapper) application include comprehensive bidirectional test capabilities. For example, the MaxTester 715B last-mile singlemode OTDR offers dynamic range up to 30 dB, and short event and attenuation dead zones. EXFO's FastReporter3 is a powerful data post-processing application useful for bidirectional batch analysis for EXFO's OTDR/iOLM test instruments (supporting Bellcore/Telcordia.sor, .iOLM and .trc file types), available at no cost from the EXFO Apps website.

Conclusion

It is hoped this application note has reduced any confusion around OTDR gainers, how they occur, and how to mitigate them using EXFO industry-leading test equipment and software applications.