Explanation of Reflection Features in Optical Fiber as Sometimes Observed in OTDR Measurement Traces

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Background & Summary

Starting with the basics of how OTDR fiber measurements are made and interpreted, this White Paper explains how reflection features are sometimes observed in optical fibers, how these features may be characterized by OTDR measurements and, if present, how they can be verified to conform to ORL specifications (and satisfy all relevant international standards and system performance requirements). Small reflections within a relatively long length of fiber do not have appreciable amplitude (height) as viewed on an OTDR trace using longer pulse widths that are necessary during fiber production measurements. These same small and passing reflections may be found with smaller pulse widths during subsequent cabling or installation measurements on shorter fiber lengths, and they do not pose any risk to transmission capability or mechanical reliability. For this reason, small reflection events with zero attenuation change are not systematically removed, and do not alter fiber attenuation behavior. It is not considered cost effective, or advantageous from a performance or reliability perspective, to actively seek and remove sections of fiber or cable with these small reflection features.

Introduction: OTDR - Measurement Interpretation Basics

In order to understand how features in fibers are detected by an OTDR (optical time-domain reflectrometer) and how the results should be interpreted, it is first necessary to understand the basics of how a fiber measurement is made using an OTDR. In very simple terms, an OTDR consists of a laser light source and an optical detector, together with electronic and software driven controls. The OTDR injects an accurately timed light pulse into the fiber and the optical detector observes the small proportion of light that is reflected backwards (backscatter) as the forward propagating pulse travels along the fiber being measured. The amount of light that is backscattered is a tiny fraction of the input pulse, typically less than one millionth (< 0.000001% or < -79 dB).

The rms (root-mean squared) duration of the light pulse is called the "pulse width" and is quantified in units of time, typically nano- (10^{-9}) or pico- (10^{-12}) seconds. The amplitude of the reflected light seen by the OTDR detector, together with the corresponding time delay (from when the input pulse was triggered), is recorded and the time delay is converted into distance travelled using the known speed with which the light travels along the fiber. The OTDR is pre-programmed with the IOR (optical index of refraction) value for the fiber to enable the OTDR to calculate and display the length and position of any events (observed as regions of higher or lower levels of reflected or backscattered light) as the measurement pulse travels along the fiber. The specific IOR values used depends on fiber type and measurement wavelength (IOR values are generally provided in product information sheets available from the Corning Optical Fiber web site). Figure 1 shows how light travelling along a single-mode fiber may be reflected back towards the OTDR detector due to: a) *Rayleigh Scattering* due to non-homogeneous structural changes at the molecular level, b) *Reflections* due to localized changes in the refractive index of the glass, c) *MFD (mode field diameter) variations* caused by glass geometrical changes/ differences or d) *Fresnel peak*s, where there is a sudden change in material density,

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e.g. from glass-to-air transitions at near-perpendicular cleaved fiber ends. In field deployed cabled fibers, OTDRs can be used to locate other extrinsic events such as splices, cable joints, and connectors.

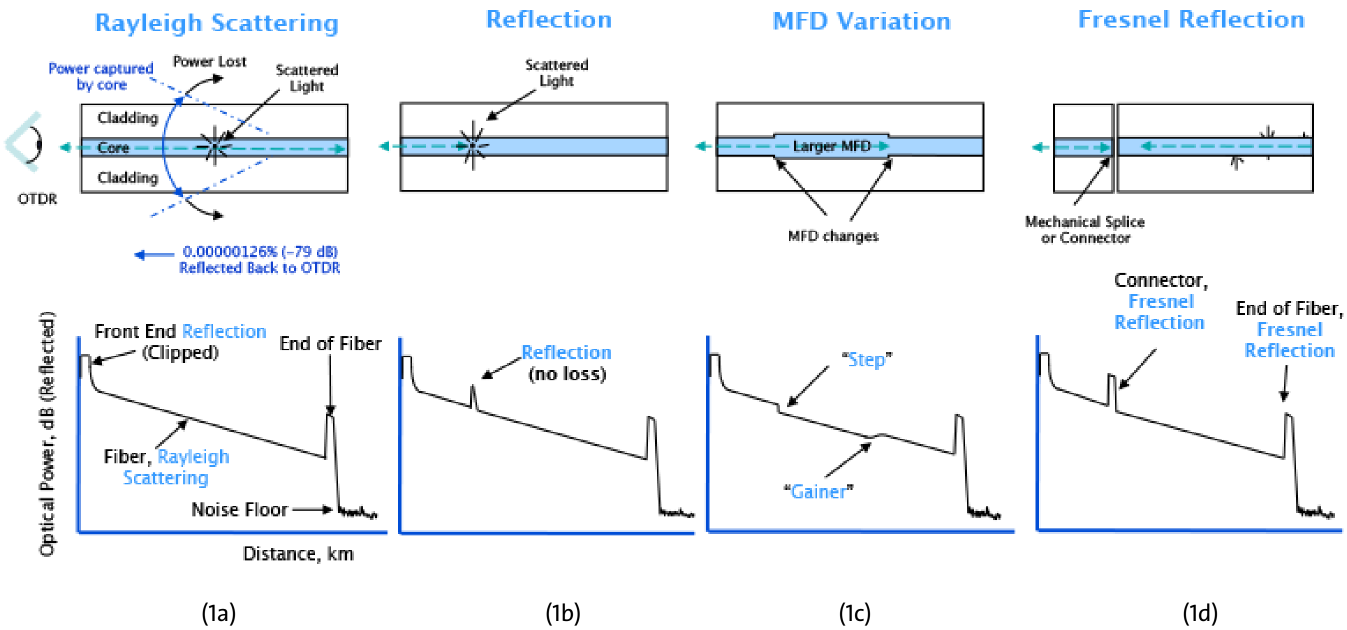

Figure 1. OTDR trace interpretation of features or events in an optical fiber path.

Reflections are not Point Defects

Reflective events in OTDR traces are often misdiagnosed as point defects or Fresnel peaks in the fiber, when in fact small level reflections are not point defects and are distinguishable by the appearance of a peak in the trace but with zero or very near zero attenuation loss (figure 1b). The IEC international industry standard (for measurement methods and test procedures for attenuation), using the backscatter "method C" [1] refers to these events as "point discontinuities", and features with attenuation change as "attenuation non-uniformity".

A small reflection is typically caused by a localized refractive index change in the light carrying region of the fiber. The propagating light signal, which experiences a small instantaneous change in the refractive index, changes the proportion of light that is backscattered to the OTDR detector, hence, the instantaneous peak of backscattered light is associated with zero or near-zero loss. A less likely possibility is that the feature is the result of a small void in the light carrying region. In either case, reflective features have been investigated extensively by Corning and the global industry over the past 45 years of fiber manufacturing, concluding that these reflective features do not represent an optical performance or mechanical strength risk as the strength and fatigue properties are determined only by flaws at the surface of the glass. From the fundamentals of fracture mechanics, any degradation of the strength of a fiber requires the presence of a glass surface flaw and moisture. Since all Corning fiber is strength tested to at least 100 kpsi, customers can be assured that any glass surface flaws of appreciable size (< 1 μm) have been removed during the fiber manufacturing process.

The amount of backscattered light is inversely proportional to the mode field diameter (MFD) and so a fiber with a smaller MFD carries a larger optical power density in the core and an OTDR detector will see proportionally more backscattered light than a larger MFD fiber;

$$\text{Backscatter Level } \alpha \ \frac{\text{incident power}}{\text{MFD}}$$

Therefore, when measuring splice loss, it is recommended to take the average of bi-directional OTDR traces to account for possible MFD variances between different sections of fiber, e.g. large-MFD to small-MFD, which registers an increase in backscatter (figure 1c), also known as "gainers" [2].

Reflection Amplitude – ORL Specifications

Whilst a small reflection causes no impairment to the forward propagating light signal, the ORL (optical return loss) specification of the fiber ensures that the magnitude of the reflected light is sufficiently small not to interfere with laser-based transmitters, or other optical modulation devices that may otherwise cause transmission impairment in practical systems. The ORL value (dB) is different from the amplitude of the reflection as seen by an OTDR as a peak in the base-line backscatter level. OTDR measurements during cable manufacture and cable testing almost always use a shorter pulse width as compared to Corning fiber production OTDR measurements. Corning has to employ a longer pulse width (ex. 500 to 1,000 ns) in order to accurately measure long lengths of fiber that are manufactured up to 63.0 km. The amplitude of a reflective feature on an OTDR trace appears larger when measured by shorter pulse widths and therefore are often misinterpreted as a cause for concern during cabling or installation measurements.

Corning uses the definition of ORL to determine the overall magnitude of the reflected light in a manner which is independent of OTDR pulse width and the corresponding recorded reflection peak. ORL is related to the magnitude of the overall backscattered light;

$$\mathrm{ORL(dB)} = 10 \cdot \log_{10} \left[\frac{\text{incident power} + \text{backscatter}}{\text{backscatter}} \right]$$

Whereas the height of a reflection peak on an OTDR trace, A (dB), as measured above the backscattering level, as shown in figure 2, is given by;

$$A\mathrm{(dB)} = 5 \cdot \log_{10} \left[\frac{\text{reflection} + \text{backscatter}}{\text{backscatter}} \right]$$

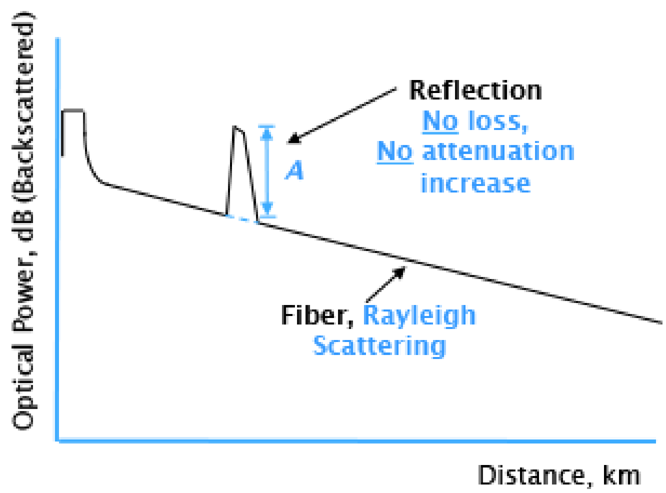

Figure 2. Determination of ORL value of a reflection feature using an OTDR measurement trace.

The ORL value for a reflection feature may be calculated from the height of a reflection detected by an OTDR (figure 2);

$$\mathrm{ORL(dB)} = B - 10 \cdot \log_{10} \left[\left(10^{\frac{A}{5}} - 1 \right) \cdot w \right] \qquad (1)$$

Where:

B = Rayleigh backscatter coefficient (in dB) of the fiber under test (see table 1),
A = Reflection amplitude (in dB), as measured by the OTDR,
w = OTDR measurement pulse width (in nanoseconds).

Table 1. Typical Rayleigh Backscatter and ORL values for Corning fibers

Product Type	Rayleigh Backscatter Coefficient, B (dB), [1 ns pulse width]				Corning ORL Specification (dB)
	850 nm	1310 nm	1550 nm	1625 nm	
SMF-28e+® fiber	–	77	82	83	≤-60
SMF-28e+® LL fiber					
SMF-28® Ultra fiber					
SMF-28® Ultra 200 fiber					
SMF-28® ULL fiber					
ClearCurve® LBL fiber					
ClearCurve® ZBL fiber					
LEAF® fiber	–	75	81	82	≤-60
All 62.5/125 fibers	68	76	–	–	See note
All 50/125 fiber	68	76	–	–	

Note: Corning's ORL assessment for multimode fibers is based on exceeding requirements for IEEE Ethernet applications [4].

Table 2 shows how reflections at or below the -60 dB ORL threshold in single-mode fiber, may appear larger in amplitude when OTDR measurements are taken using shorter pulse widths. A small level reflection feature, with peak amplitude of ≤0.05 dB, observed during OTDR inspection, using a narrow pulse width of 100 ns or lower, can be misinterpreted as failing fiber attenuation specifications. However, as shown in table 2 below, the maximum peak amplitude resulting from a the maximum -60 dB ORL specification reflective feature is pulse width dependent and an amplitude of up to 2.06 dB at 1550 nm for a 100 ns pulse width, as calculated using (1) above. Figure 3 also shows that the amplitude of reflection feature is dependent on pulse width and a peak amplitude of 0.1 dB at 1550 nm, measured with a 100 ns pulse in single-mode fiber is less than -75 dB ORL.

Table 2. Calculated Reflection Height with OTDR Pulse Width (SMF-28e+ fiber)

OTDR Pulse duration (ns)	OTDR Pulse width (meters)	Reflection height, 1310 nm (dB)	Reflection height, 1550 nm (dB)
100	10	≤ 0.88	≤ 2.06
200	20	≤ 0.49	≤ 1.27
500	50	≤ 0.21	≤ 0.60
1,000	100	≤ 0.11	≤ 0.32

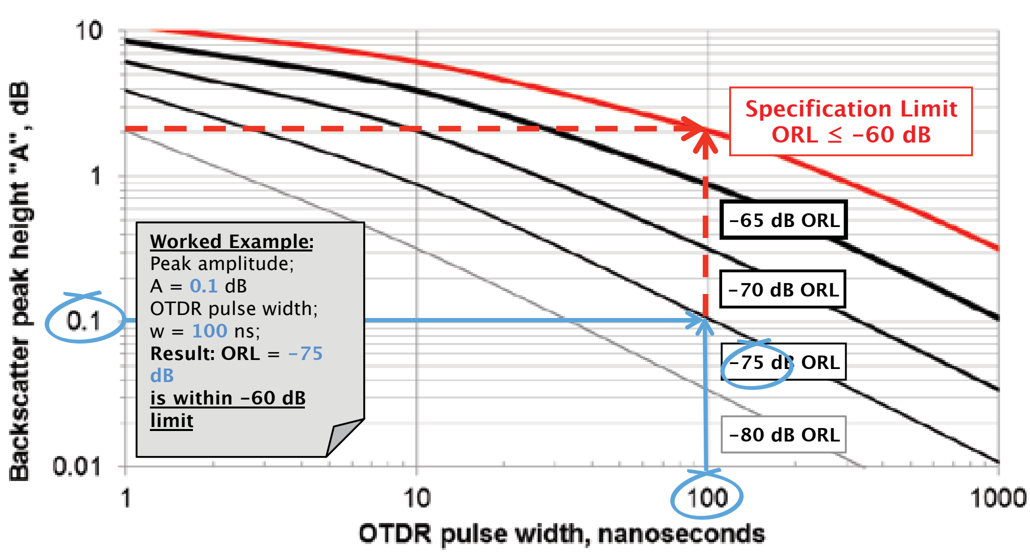

Figure 3. Graphical relationship between; OTDR trace reflection height, pulse width & ORL.

ORL Requirements for Practical Transmission Systems

The Corning specification of ORL (absolute value) is ≤ -60 dB for all single-mode fiber types, which is more stringent than the published international standards requirements of -27 dB [3] and -32 dB [4] for single-mode based transmission systems. An ORL value of -27 dB is equivalent to an OTDR measurement peak of 15 dB at 1310 nm using a pulse width of 100 ns. For multimode fiber-based systems the tolerance to optical reflections is much greater owing to the lower output power of LED (light emitting diode) and VCSEL laser transceivers designed for short reach applications. For some transmission protocols, ORL is not specified and instead there is greater focus on the return loss of connectors that are more commonly used in multimode fiber links. For example, the IEEE 100G Ethernet standards specifies a maximum discrete ORL value of -20 dB [5].

Conclusion

Reflections below Corning's ORL specification are considered benign (non-harmful) to the fiber strength or optical transmission properties of the fiber. Fiber containing reflections smaller than the threshold specification are not actively removed during fiber production. Shorter OTDR pulse widths cause the amplitude of the reflection to appear larger. Corning's ORL specification is independent of the pulse width and complements Corning's additional specifications for attenuation point discontinuities. Corning specifies fiber ORL values that exceed international standards (ex. ITU G.957 [3] and IEEE Ethernet 802.3ba [5]), which ensure that even multiple reflection features remain non-functional relative to practical optical fiber transmission requirements. In summary, small reflections are cosmetic features as viewed on an OTDR trace, and do not represent a functional concern with the fiber.

References

[1] "Measurement methods and test procedures - Attenuation (Requirements specific to method C - Backscattering)", IEC 60793-1-40, 2001.

[2] "OTDR Gainers – What Are They ?", Corning Application Note, AN3060, Match 2014, which is published on the Corning website: www.corning.com

[3] Optical interfaces for equipment and systems relating to the synchronous digital hierarchy, ITU-T Recommendation G.957, Published April 2006.

[4] Broadband optical access systems based on Passive Optical Networks (PON), ITU-T Recommendation G.983.2, Published January 2005.

[5] IEEE 802.3ba 40 and 100 Gigabit Ethernet Standard, Published June 2010.

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