

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

## White Paper

Dr. Russell Ellis

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### Background

Starting with the very basics of how OTDR fiber measurements are made and interpreted, this White Paper explains how reflection features are sometimes observed in optical fibers, how reflections may be characterized by OTDR measurements and, if present, how they can be related to Corning ORL specifications (and also recommendations in relevant international standards). Typically, low-level reflections pose no risk to transmission impairment in practical communication systems.

### Introduction: OTDR - Measurement Interpretation Basics

In order to understand how features in fibers are detected by an OTDR (optical time-domain reflectometer) 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 rms 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 traveled 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 down the fiber. By some conventions, the IOR can also be used to define the pulse width in units of length, typically meters, using the equation;

$$\text{Pulse width (length in meters)} = \frac{w \cdot c}{2 \cdot n}$$

Where;  $w$  = the pulse width in units of time,  $c$  = the free space velocity of light and  $n$  = the group index of refraction of the fiber (at the measurement wavelength). This is done to determine precision of length and distance estimations of features observed by OTDR measurements such as fiber breaks, splices, etc. Note dividing by 2 is used to account for the bi-directional path of the measurement pulse and is a convention among OTDR manufacturers and users. It should not be confused with the free space length,  $L = w \cdot c/n$ .

The specific IOR values used depends on fiber type and measurement wavelength (IOR values for all Corning optical fiber products are specified in product information sheets and are available from the Corning Optical Fiber web site). Figure 1 shows how light traveling along a single-mode fiber maybe 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 optical refractive index of the glass, c) *MFD (mode field diameter) variations* caused by glass geometrical changes/differences or d) *Fresnel peaks*, where there is a sudden change in material density, e.g. from glass-to-air transitions at near-perpendicular cleaved fiber ends.

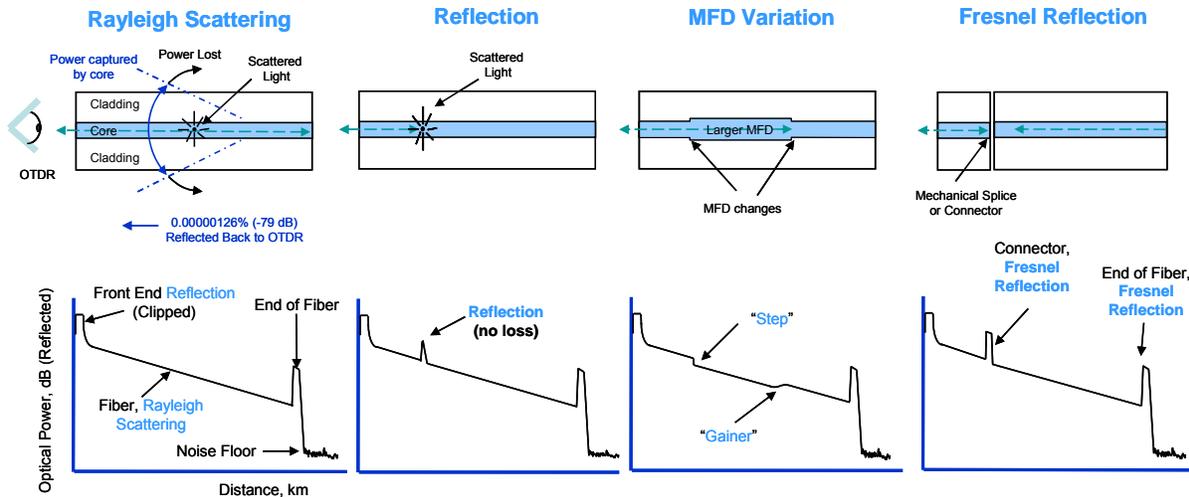


Figure 1. OTDR trace interpretation of features or event in an optical fiber path.

## Reflections are not Point Defects

Reflective events in OTDR traces are often misdiagnosed as point defects in the fiber, when in fact 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). In this type of scenario a reflection is often caused by the presence of a particle situated at or around the core-cladding interface and may occur in single-mode or multimode fiber types. The propagating light, experiencing a small instantaneous change in the refractive index of the core, changes the proportion of light that is backscattered to the OTDR detector, hence the instantaneous peak of backscattered light is associated with near-zero loss. A less likely possibility is that the feature is the result of a small void in the core region. In either case, reflective features have been investigated extensively by Corning during more than 25 years of fiber manufacture, concluding that internal particles or voids do not present an increased risk of mechanical weakness or fatigue as the strength and fatigue properties are determined only by flaws at the surface of the glass. This is because any degradation of the strength of a fiber requires the presence of moisture, which may be present in flaws at the surface of the glass but not those which are internal.

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;

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

Therefore, when measuring splice losses, it is recommended to take the average of bi-directional OTDR traces to take account of 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” [1].

### Reflection Amplitude – ORL Specifications

Whilst a 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 to the amplitude of the reflection as seen by an OTDR as a peak in the base-line backscatter level. As it is often the case that during cable manufacture and cable testing, OTDR measurements are made using shorter pulse widths, typically 100ns, permitted given the shorter length of fiber under test, typically < 8km. Corning has to employ a longer pulse width (0.5µs) in order to measure the long lengths of fiber that are manufactured (up to 50.4km for single-mode and 17.6km for multimode fibers). Reflective features appear larger when measured by shorter pulse widths and therefore are often misinterpreted as more significant features on the OTDR trace.

Corning uses the definition of ORL attribute 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 light backscattered;

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

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;

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

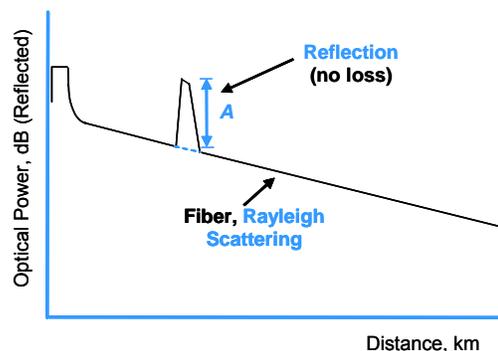


Figure 2. Determination of ORL value of a reflection feature using an OTDR measurement trace.

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

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

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. Raleigh Back Scatter and ORL specification values for Corning fibers.**

Product Type	Rayleigh Backscatter Coefficient, B (dB)				Corning ORL Specification (dB)
	850nm	1310nm	1550nm	1625nm	
SMF-28® fiber	-	77	82	83	≤-60
SMF-28e® fiber					
NexCor® fiber					
SMF-28e+™ fiber					
SMF-28e® XB 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 [3].

Table 2 shows how reflections at or below the -60dB ORL threshold in single-mode fiber may appear larger in amplitude when OTDR measurements are taken using narrower pulse widths. The longer pulse width is used by Corning to achieve measurement capability over reel lengths up to 50.4km for single-mode fiber.

**Table 2. Calculated reflection height with OTDR pulse width (SMF-28e+ fiber).**

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

Corning measurement |

### ORL Requirements for Practical Transmission Systems

The Corning specification of ORL (absolute value) is ≤-60dB for all single-mode fiber types which exceeds international standards requirements of -27dB [2] for single-mode based transmission systems. An ORL value of -27dB is equivalent to an OTDR measurement peak of 15dB at 1310nm using a pulse width of 100ns. 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 laser transceivers designed for short reach applications. For some protocols ORL is not specified and instead there is greater focus on the return loss of connectors which are more commonly used in multimode fiber links. For example, Fiber Channel and the IEEE 10G Ethernet standards both specify an ORL value of -12dB [3]. This is equivalent to an OTDR trace reflection peak of up to 22dB when using a pulse width of 200ns. During fiber manufacture, because of the much relaxed reflection requirements of

multimode-based systems, Corning adopts a flexible ORL quality architecture and uses the -60dB single-mode ORL specification as an internal comparison to ensure that any reflection features, if present, are well below the -12dB requirement.

## Conclusion

Reflections below Corning's ORL specification are considered non-harmful to the fiber strength or transmission properties of the fiber. Occasional regions of fiber exhibiting reflections smaller than the threshold specification are not actively removed from delivered lengths. Shorter OTDR pulse widths cause the amplitude of the reflection to appear larger. Corning's ORL specification is independent of the pulse width and is in addition to Corning's additional specifications for attenuation point discontinuities. Corning has adopted ORL specification values which ensure that even fibers with multiple reflection features remain non-functional relative to practical transmission requirements. Corning's ORL specifications are much more stringent than those recommended by international standards, for example ITU G.597 [2] and IEEE Ethernet 802.3ae [3]. Small reflections are cosmetic and do not represent a functional concern with the fiber.

## References

- [1] "OTDR Gainers - What are they?", Corning Application Note AN30260 July 2001: [http://www.corning.com/docs/opticalfiber/an3060\\_07-01.pdf](http://www.corning.com/docs/opticalfiber/an3060_07-01.pdf)
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