

Lorenz Cartellieri / Experior Photonics, Inc.
Optical Return Loss Meters
Measurement and Application Issues

Contents

1	Scope	3
1.1	Optical Return Loss and Reflectance	4
2	Measuring Optical Return Loss and Reflectance	5
2.1	The Continuous Wave (CW)-Based Instrument.....	6
2.2	Optical Time Domain Based Instruments	8
2.2.1	Time Domain Based Instruments Measuring Backscatter	8
2.2.2	Time Domain Based Instruments Not Considering Backscatter	10
3	Measurement Limitations and Applications	11
3.1	General and Definitions	11
3.2	Application Issues Using the OCWR Method	12
3.3	Application Issues Using Time Domain Based Return Loss Meters	15
3.3.1	OTDR (Backscatter Method)	15
3.3.2	OTDR (Reflective Event Comparison Method).....	20
4	Calibration Issues and Industry Status	22
4.1	Reference Cables / Reference Jumpers.....	24
5	References.....	25
5.1	Normative References.....	25
5.2	Other References	25

Figures

Figure 1: Visualization of Reflectance with A) pulsed & B) continuous stimulus	4
Figure 2: Visualization of Optical Return Loss with A) pulsed & B) continuous stimulus	5
Figure 3: OCWR Block Diagram	6
Figure 4: OTDR Block Diagram (Backscatter Method).....	9
Figure 5: OTDR Block Diagram (Reflective Event Comparison Method)	10
Figure 7: Backscatter Level as Function of OTDR Pulse Length in Singlemode Fiber.	16
Figure 9: OTDR Trace Signature of 4.75km Span (No Deadzone Box & Terminator)...	18
Figure 10: OTDR Trace Signature of 4.75km Span (w. Deadzone Box & Terminator)..	19
Figure 11: Generic Calibration Set-up for Return Loss Meters.....	23

Tables

Table 1: OTDR Performance Criteria	9
Table 2. Limitations of Effectiveness & Feasibility of Optical Termination Techniques	12
Table 3. Effectiveness of Mandrel Terminator vs. Index Matching Block	12
Table 4. Measurements on Cables Using Reflective Event Comparison Method	21

1 Scope

To ensure the proper performance of optical transmission systems, optical return loss is measured at the component level and at the installed fiber plant. Reflected optical power contributes to the loss of optical power within the fiber optic system and in higher speed transmission systems, in particular, can cause interference during signal processing. In order to ensure that a fiber optic network exhibits little back reflection, the total optical return loss of the network must be controlled and verified. Various types of instruments are used within the fiber optics industry to measure the return loss and/or reflectance of fiber optic components, assemblies, and systems.

The purpose of this white paper is to build awareness of the performance and application issues affecting instruments used to measure optical return loss and reflectance on both the component and the system level. Different instruments may be used to measure optical return loss and reflectance of system components such as connectors, filters, isolators, diodes, subsystems, cable assemblies, and an entire fiber span. Under certain circumstances, these instruments might measure the reflection of a point defect, or the cumulative reflected power of a whole system.

In order to compare the performance criteria of instruments used to measure optical return loss and to develop an understanding of their functionality and the measurement uncertainty associated with their use, some terminology and common application issues are collected. It is the intent of this paper to combine criteria, parameters, and issues that help users of these test instruments understand common phenomena associated with them.

In order to build awareness about common issues with using instruments used to measure optical return loss this paper addresses:

- * What optical return loss is
- * When and where optical return loss is measured
- * The various kinds of instruments used to measure optical return loss
- * Performance criteria
- * Calibration issues
- * Applications issues
- * The industrial status of instruments used to measure optical return loss

1.1 Optical Return Loss and Reflectance

Various mechanisms contribute to the attenuation, or loss of signal power, along a fiber span. This paper is concerned with those mechanisms that reflect or scatter light back towards the light source.

The return loss of a device, measured in dB, is the logarithmic ratio between the forward signal power before the device and the signal power being reflected/scattered back towards the light source by the device. The device can be an entire fiber optic span, a portion of the span, or a single point or object within the span.

When the device exhibits a single Fresnel event, the term “Reflectance” is used to describe the logarithmic ratio of the reflected signal power to the incident signal power at the input of the device. A Fresnel reflection is caused by a change in refractive indexes like the one caused by a glass to air interface at the end of a fiber, contamination at connector interfaces or over-polished connectors.

Figure 1 depicts the reflection of an optical signal at a device with a single event. The event is a mismatch in refractive indexes. Part A) shows a graphic representation of a pulsed stimulus. Part B) shows a graphic representation of a continuous wave stimulus. In both cases only one single event causes the optical signal to be reflected back and therefore Reflectance is used to describe the relative magnitude of the reflected power.

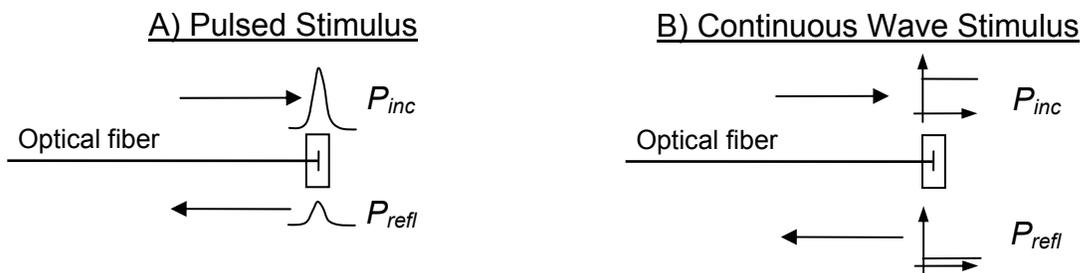


Figure 1: Visualization of Reflectance with A) pulsed & B) continuous stimulus

When the device includes more than one Fresnel event, the term “Optical Return Loss” or ORL is used to describe the relative magnitude of the cumulative reflected and backscattered signal power at the input of the device. Optical Return Loss is the logarithmic ratio of the incident optical power to the total reflected signal power caused by all components under test including the backscattered signal from the fiber itself at the input of the device under test.

Figure 2 depicts the Optical Return Loss of a device that includes multiple events with the events being mismatches in refractive indexes. Part A) shows a graphic representation of a pulsed stimulus. The energy of all individual events must be integrated together in order to calculate the Optical Return Loss of the device. Part B) shows a graphic representation of a continuous wave stimulus. In both cases multiple

events cause the optical signal to be reflected back and therefore Optical Return Loss is used to describe the relative magnitude of the reflected power.

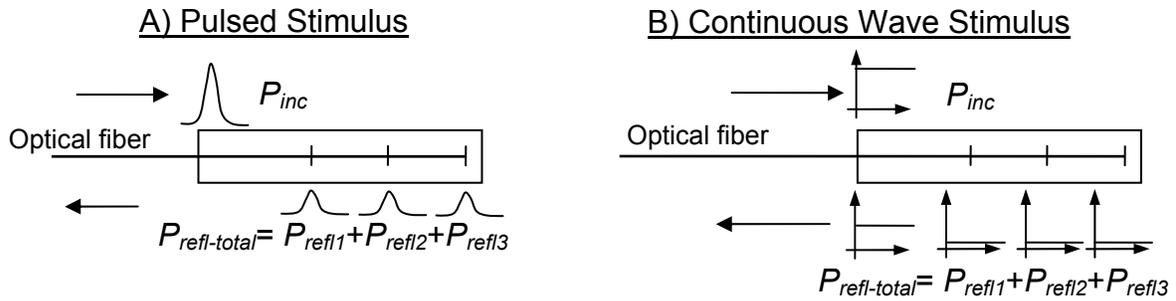


Figure 2: Visualization of Optical Return Loss with A) pulsed & B) continuous stimulus

Figure 2 does not show the backscattered signal power from the fiber itself, which is included when measuring Optical Return Loss. Backscatter occurs along the fiber media itself due to density fluctuations. The magnitude of the backscatter is a property of the fiber and can be calculated for a given fiber type, transmission wavelength, and forward transmitted optical power.

Reflectance has a negative value:

$$Reflectance [dB] = 10 \cdot \log\left(\frac{P_{refl}}{P_{inc}}\right) \leq 0$$

Optical Return Loss has a positive value:

$$Optical Return Loss [dB] = 10 \cdot \log\left(\frac{P_{inc}}{P_{refl-total}}\right) \geq 0$$

For the measurement of passive components, the magnitude of reflected and/or scattered signal power, whether from a single event or cumulative, is always smaller than the incident forward transmitted signal power. P_{inc} is the optical power in forward direction measured at the input of the device. $P_{refl-total}$ is the optical power reflected back towards the transmitting source of energy measured at the input of the device.

2 Measuring Optical Return Loss and Reflectance

Optical return loss and reflectance can be measured in multiple ways. Commonly used test instruments might measure optical return loss or only reflectance based on their underlying concept, technology, or the application within which they are used. The most commonly applied technologies will be introduced before discussing the circumstances where these instruments can be used to measure reflectance or optical return loss. It is

important to understand the differences between them when choosing the proper instrument for a given test or measurement.

A distinction is made between return loss meters that use continuous wave technology and instruments that operate in the time domain (transmit pulsed light signals). The second method includes the OTDR (Optical Time-Domain Reflectometer). OTDRs can be used to measure reflectance and often even optical return loss, but are not classified as Optical Return Loss Meters. Due to the OTDR's ability to measure return loss it is included in this technical system bulletin. Since measuring return loss and reflectance using continuous wave based Optical Return Loss Meters and time domain based instruments is fundamentally different, the paper will address the issues separately. Two other, less common methods that can be used to measure return loss are the OLCR (Optical Low Coherence Reflectometry) and the OFDR (Optical Frequency Domain Reflectometry). Precision Reflectometry is touched upon only briefly in section 3.3.1 and is not within the scope of this document.

2.1 The Continuous Wave (CW)-Based Instrument

Figure 3 is representative of a circuit that may be used for OCWR (Optical Continuous Wave Reflectometer) measurements. It is described per FOTP-107, IEC 61300-3-6, and Telecordia TR-TSY-001028 (listing generic criteria) and is based on the use of five basic components. 1) A continuous wave stabilized light source, 2) an optical branching device, 3) an optical power meter, 4) a process controller, and 5) a display.

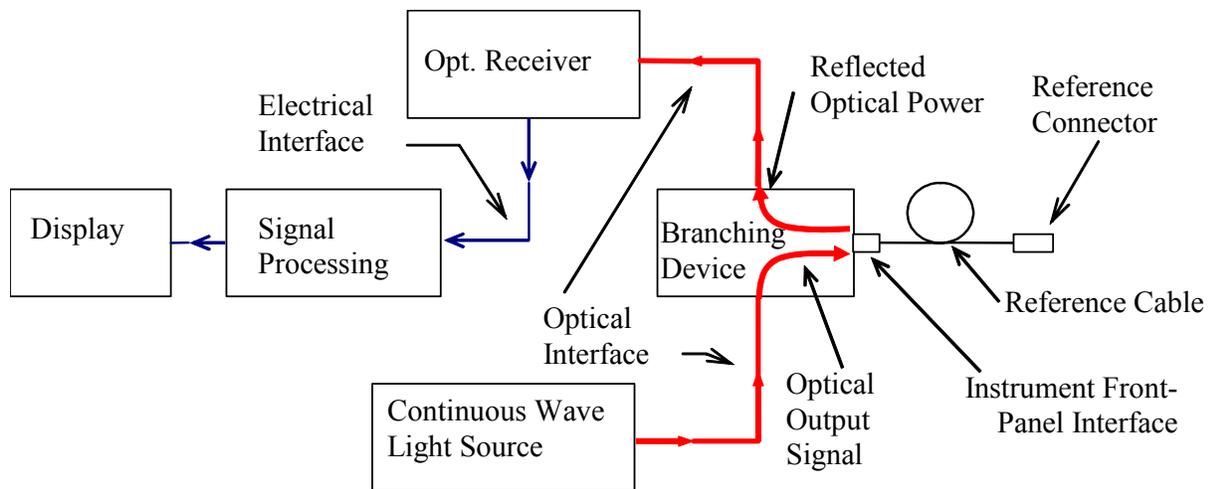


Figure 3: OCWR Block Diagram

Three steps are necessary in order to measure the optical return loss or reflectance of a reflective event or system:

1) A mandrel wrap is applied to the end of the reference cable just before the reference connector. This is to optically isolate the return loss meter from the reflection occurring

at the end of the reference cable. Once the mandrel wrap is in place the optical power meter measures the level of reflected optical power (Z) that is inherent to the internals of the test instrument [e.g. in mW] including the optical power reflected at the front panel interface mating between the reference cable and the instrument. This measurement step is also called “zeroing” the instrument. Note that the term “mandrel wrap” is used to describe an optical terminator with an insertion loss of not less than 60dB.

2) Remove the mandrel wrap from the reference cable. Make sure the reference connector is clean and without scratches and take a reference optical power measurement (R). This will measure the amount of reflected optical power from all internal reflections and from the reference connector [in mW]. The reference connector must exhibit a reflection of known magnitude. Typically a flat polished connector is used exhibiting approximately 14 dB return loss.

3) Connect the reflective event or system that is to be evaluated (device under test or DUT) to the master plug (reference connector). Apply a mandrel wrap termination shortly after the DUT. Take an optical power measurement (D) [in mW].

The measured return loss results from the following relationship:

$$RL = -10 \cdot \log \left(\frac{D - Z}{\left(\frac{R - Z}{|-4\%|} \right)} \right) = -10 \cdot \log \left(\frac{D - Z}{(R - Z) \cdot 25} \right) \quad [dB]$$

The above formula differs from the one illustrated in the IEC document 61300-3-6 since it is describing an instrument that uses an internal reference reflection. If the test device constitutes only a single Fresnel reflection, hence measuring its reflectance, by definition the result should be negative. Since the type of device under test is unknown to the instrument, all test results are displayed in positive values.

The 4% reflectivity of the glass to air interface is approximate. This value assumes the refractive index of the fiber core to be 1.5. If, for example, the refractive index of the fiber used is 1.47, about -3.6% of the light are reflected at the glass to air interface. This text uses 4 %, or -14 dB. Many different fiber types are used and the refractive index can vary, therefore -14 dB is used for simplicity. Assumed is further that the reference connector is polished flat. An angle polished connector (APC = angle physical contact) does not exhibit a significant reflection from its glass to air interface. While depending on the refractive index of the core, the quality of the polish, and the accuracy of the typically 8° angle, the reflectance of an unmated (to air) APC connector is >-55 dB.

While return loss meters based on OCWR measure ORL, they are also capable of measuring reflectance. If for example the device under test constitutes only a single connector and a mandrel wrap is placed within a short distance after the connector, its reflectance is measured (see Figure 1 B). However, test results are typically displayed

positive. This has led the industry to record return loss in positive values even if the DUT exhibits a single reflection. Note that the accuracy of the return loss measurement using the OCWR method depends on the quality (effectiveness) of the mandrel wrap (mandrel terminator). Multimode fiber can not be terminated using a mandrel wrap. Alternative methods like index matching gel / block can be used to provide optical termination instead. See discussion in 3.2 below.

2.2 Optical Time Domain Based Instruments

Generically, an optical time domain based instrument is able to spatially resolve and evaluate a component or feature along a length of fiber. This document addresses application issues regarding time domain based instruments and these application issues vary depending on the particular measurement method used by the OTDR. In order to make a distinction between the different measurement methods and to allow addressing the different issues related to those differences, the following two measurement categories for evaluating reflective events are used.

1. Traditional Backscatter Method described in FOTP-8
2. Reflective Event Comparison Method.

OTDRs using the traditional backscatter method in the first category are measuring the backscatter level of the fiber media itself and the reflection peak level of reflective events along the fiber optic link. The information is used to display a trace signature representing the losses and reflections occurring along the fiber optic link.

OTDRs implementing the Reflective Event Comparison Method in the second category are far less common and are typically optimized for measuring short-length optical links like patch cords, pigtailed, and other discrete components. This results in improved spatial resolution needed to resolve closely spaced reflective events accurately. In the Reflective Event Comparison Method the backscatter signal of the fiber media itself is not measured. Rather, the relative magnitude of two reflective events of which one reflective event has a known magnitude is compared. The reflective event of known magnitude (reference reflection) can lie inside or outside of the test instrument.

It shall be noted here that the term “Reflective Event Comparison” is not typically used in the industry today. The term is used in this document merely to allow a distinction between two different methods and to allow addressing application issues that are unique to one or the other method separately.

2.2.1 Time Domain Based Instruments Measuring Backscatter

Current standards literature defines that return loss measurements using OTDRs are based on the measurement of the Fresnel reflection height with respect to the backscattering level. The backscattering level is a function of the selected pulse width and the backscattering coefficient of the fiber.

The OTDR (Optical Time-Domain Reflectometer) method as described per FOTP-8, IEC 61300-3-6, and Telecordia TR-NWT-000196 (listing generic criteria), fundamentally requires 1) a pulsed light source, 2) an optical branching device, 3) a photo diode, 4) a process controller, and 5) a display.

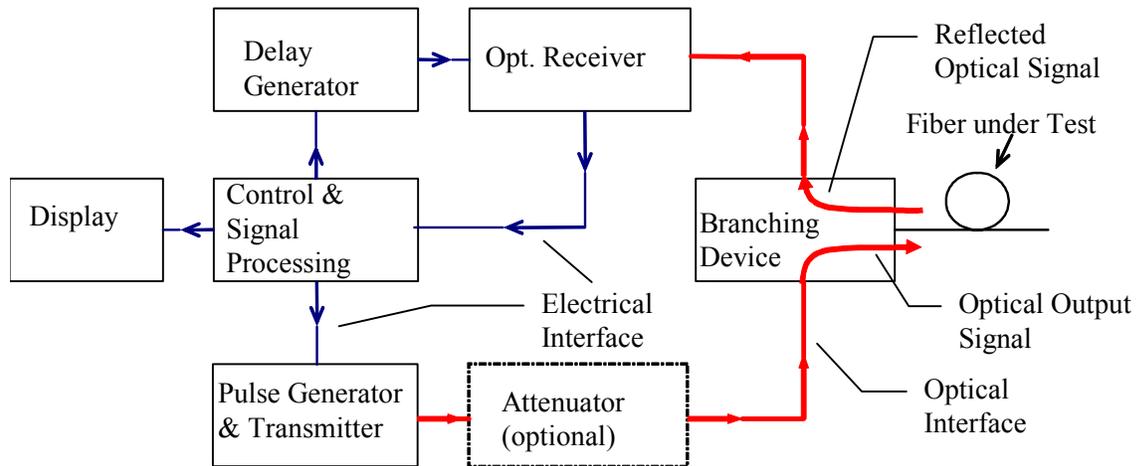


Figure 4: OTDR Block Diagram (Backscatter Method)

The OTDR operates in the time domain. This and the fact that it measures the backscatter signal from the fiber itself, enables the measurement of single reflective events without de-mating optical interconnections. This advantage makes the OTDR useful in the evaluation of reflections that are located within the installed optical network. Either a PC-OTDR (photon counting) or network OTDR can be used depending on the required spatial resolution, return loss measurement range, and the length of the cable assembly under test. A Network OTDR is typically portable and used in the outside plant industry to verify and troubleshoot the optical network and fiber plant. PC-OTDRs find application in optical component, module, and subsystem troubleshooting and design where individual reflections are often closely spaced. PC-OTDRs are also used in applications where short lengths of fiber need to be measured with increased precision. The following table summarizes performance criteria that differentiate the two OTDR types:

	Max Spatial Resolution	Reflection Sensitivity	Reflectance Measurement Range	Optical Pulse Length	Max Length of DUT
Network OTDR	>1 m	-60 dB	≈50 dB	≥10 ns	<100 km
PC-OTDR	≈10 mm	<-120 dB	≈60 dB	≤10 ns	<200 m

Table 1: OTDR Performance Criteria

The application typically determines which instrument is applicable given the different performance criteria of these methods.

2.2.2 Time Domain Based Instruments Not Considering Backscatter

Unlike the traditional OTDR discussed in the previous section, OTDRs using the Reflective Event Comparison Method measure return loss but return loss measurements are not based on the fiber backscattering level. While a return loss measurement using the OTDR technique is largely a calculation, the Reflective Event Comparison Method is based on absolute comparison between reflected energies. The magnitude of the reflection from the device under test is directly compared to the magnitude of a calibrated, or known, reference reflection. While the Backscatter Measurement Method per FOTP-8 is widely known and defined, the Reflective Event Comparison Method represents a modification designed for a specific application. In this TSB Reflective Event Comparison Method is only used to allow the differentiation between the two methods so that differences in measurement and application issues can be discussed.

The Reflective Event Comparison Method uses short pulses that enable the spatial resolution of closely spaced reflective events. The magnitude of reflections is measured based on their relative difference to a calibrated reference reflection. This is similar to the OCWR where return loss is measured based on its relative difference to a calibrated reference reflection. The reference reflection can be located at the open end of the reference jumper or inside the instrument. The Reflective Event Comparison Method fundamentally requires 1) a pulsed light source, 2) a fiber optic branching device, 3) a photo diode, 4) a process controller, 5) a display, and 6) a calibrated reference reflection.

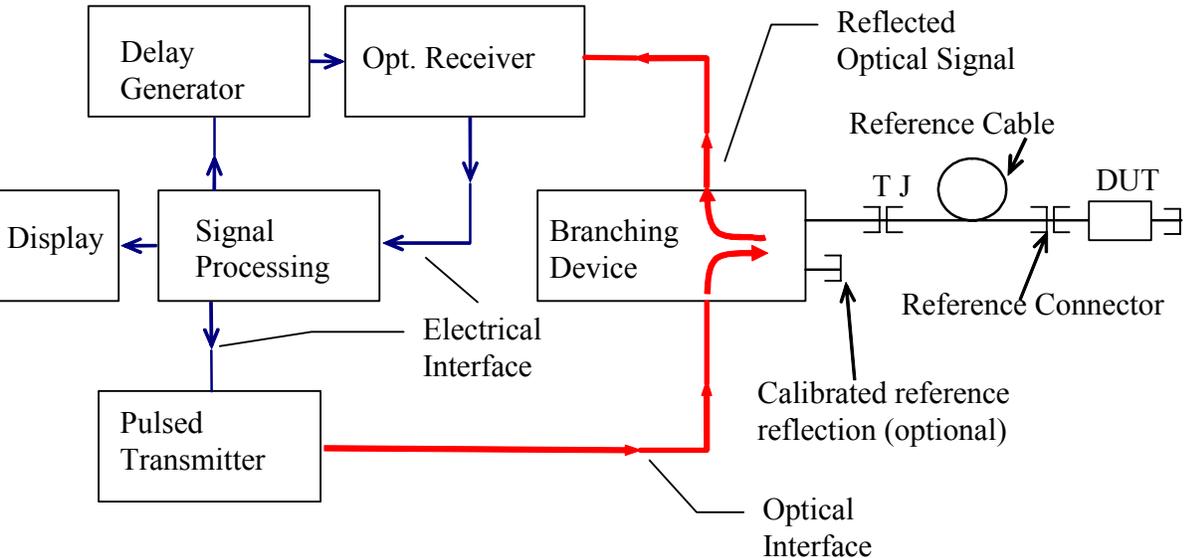


Figure 5: OTDR Block Diagram (Reflective Event Comparison Method)

The Reflective Event Comparison Method is also a time domain based method. Since it does not consider the backscattering level of the fiber for the return loss measurement, the location of the reference reflection relative to the reflection under test is critical. The optical loss or attenuation between the reference reflection and the reflection under test must be identical to the attenuation of that path present during calibration conditions. The reference reflection can be internal or external to the instrument. Internal: a calibrated reflection at the branching device serves as a reference. External: the -14 dB (approximate) reflectance of a glass-to-air Fresnel reflection can serve as a reference. If the external reflection is used as a reference, uncertainties of the fiber's refractive index can contribute to a measurement error.

3 Measurement Limitations and Applications

3.1 General and Definitions

Various applications exist for return loss measurements:

In facilities that manufacture fiber optic components (e.g. cable assemblies, connectors, collimators, isolators, multiplexers, etc.). Within the manufacturing process the return loss of the component as a whole or the reflectance of specific parts of the component is verified. Important are throughput (short testing time), accuracy, the ability to automate acquisitions, and the test procedure must not contain any practices that would damaged or alter the component under test.

In facilities that design fiber optic components for qualification testing over environmental conditions. Important are long term stability of the return loss or reflectance measurement, characterization of individual reflective sites (spatial resolution), and the ability to automate acquisitions.

In facilities that design fiber optic components throughout the design. Return loss and reflectance might be measured. Important are the accuracy of the return loss or reflectance measurement, the ability to characterize individual reflective sites (spatial resolution). For the design of wavelengths selective components, the ability to measure return loss or reflectance versus wavelength may be important.

During the installation of fiber optic networks. Mostly reflectance measurements are made for the verification of craftsmanship and system integrity. What is important here is the ability to measure reflectance of remotely located components that are not accessible and the ability to measure low reflectance devices located in long distances.

Verification of installed network performance. Mostly reflectance measurements are made for the verification of system integrity. Important are the ability to measure reflectance of remotely located components that are not accessible, the ability to measure low reflectance devices located in long distances, the full automation and integration of the test instrument in the installed network.

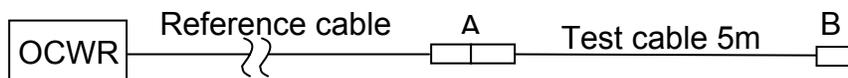
3.2 Application Issues Using the OCWR Method

This test instrument requires an optical termination that separates the fiber span under test or single event under test from the rest of the fiber optic network. This is necessary to optically separate the test device from any light being reflected or scattered back from reflective events further down in the link. Two termination types commonly used are 1) mandrel wrap and 2) index matching gel or block. Table 2 lists issues that might affect the feasibility of a required fiber termination.

Optical termination using a mandrel wrap	Optical termination using index matching gel	Termination using an index matching block
Payout Fiber / Bend-Insensitive Fiber does not exhibit bend loss. Mandrel wrap terminator will not cause the desired effect.	The matching gel may leave a residue on the polished end-face of the connector.	Issues exist when using matching blocks on fiber optic connectors that have guide pins for fiber alignment.
Non-bendable cable structure may not permit a mandrel wrap.	Backscatter of the fiber length between the reflective event and the far end of the cable might cause reflections to appear larger than they are.	
Multimode fiber can not be optically terminated through bending	The effectiveness of index matching gel to terminate reflections is limited.	
Effectiveness of the fiber termination can vary with the operator		

Table 2. Limitations of Effectiveness & Feasibility of Optical Termination Techniques

Multimode cables cannot be terminated effectively using mandrel wraps (mandrel terminator). Depending on the launch condition used to excite the multimode fiber, a mandrel wrap will introduce bend loss but never optically terminate the fiber. Index matching gel or index matching blocks offer a solution. The gel or block matches the refractive index of the fiber. This causes the light to diffuse within the gel or block without significant reflection at the optical interface. The use of index matching gel or a matching gel block as a reflection terminator does not always lead to the same test results. The following example using single mode fiber shows the test results achieved when measuring the reflectance of an optical connector A with the setup shown below using (1) a mandrel terminator right after connector A and (2) an index matching block applied to optical connector B:



Reflection Termination	Mandrel Terminator	Index Matching Block
Measured Reflectance	-49.78dB	-47.95dB

Table 3. Effectiveness of Mandrel Terminator vs. Index Matching Block

Using the index-matching block as a reflection terminator on connector B does not eliminate the backscatter signal from the test cable. Since the backscatter level of a 5-meter long patch cable (standard SM fiber) is ≈ 65 dB (1310 nm) and ≈ 68 dB (1550 nm) its contribution in this example is negligible. The discrepancy between the two measurements is due to the limited effectiveness of index matching blocks versus mandrel wraps. When multiple measurements are taken using index matching gel (or block), the highest return loss measurement result approximates potential results achieved using a mandrel wrap.

Figure 7 illustrates the limitations of index matching gel when measuring the return loss of a Fresnel event with low reflectivity, like an 8° angle polished single mode connector. A 20-meter long test cable exhibits about 58dB (at 1310nm) of backscatter signal level. A good angle polished connector exhibiting about -65 dB reflectance could not be measured using index matching gel (or block) applied to the connector on the far end of the cable. The backscatter signal from the 20-meter cable exceeds (hides) the return loss of the connector (assuming a short reference cable/jumper is used).

Obviously certain design aspects of OCWR instruments impact their overall measurement accuracy like, for example, the linearity of the internal optical detector, the sensitivity of the light source to back reflection, the output power stability of the light source, and many others. For the purpose of this document it is assumed that these, as all other discussed instruments, meet the manufacturers claimed specifications. However, certain practices associated with the use of the instrument can affect the measurement uncertainty as well. The following are possible areas that can impact the uncertainty of the ORL measurement.

- 1) Improper reference. A reference is typically taken with a flat polished connector exhibiting 14 dB of ORL. If the reference connector is not properly cleaned or polished, its actual ORL might be in excess of 14 dB or even less. This error will be carried through all subsequent measurements until the instrument is re-referenced with a properly cleaned and polished connector. To reduce the likely hood of this error, verify the geometry and cleanliness of the reference connector periodically.
- 2) Excess insertion loss at the front panel of the instrument. If the insertion loss at the bulkhead between the instrument itself and the reference cable exceeds the insertion loss present under calibration conditions of the instrument, the OCWR might have a reduced ORL measurement range. To alleviate this measure and note the absolute output power of the OCWR and check it periodically.
- 3) An improper zero measurement. An improper zero measurement can occur if the reference cable is not properly mandrel wrapped (less than 60 dB of insertion loss). This can occur if a mandrel is performed with too few turns and resulting errors are especially significant at 1310 nm. This is due to the reduced bend sensitivity of singlemode fiber at lower wavelength.

The OCWR method can be used to characterize the wavelength dependency of optical return loss for wavelength sensitive optical components and systems if the OCWR

instrument is equipped with a tunable laser. For example, wavelength dependent return loss is critical in WDM (Wavelength Division Multiplexing) and DWDM (Dense-WDM) systems. These systems use wavelength multiplexers, demultiplexers, and wavelength add-drop devices incorporating highly wavelength sensitive elements. The wavelength accuracy of the reflectivity of a diffraction grating for example is critical to the system performance and can be evaluated using a wavelength tunable OCWR instrument. WDM systems often use low coherence length DFB lasers as transmitters and are particularly sensitive to reflections. Reflections can cause multipath interference (ghost pulses) that are misinterpreted by the receiver resulting in increased bit error rate. Return Loss measurements on C-WDM (Course-WDM) devices can be challenging since only few available tunable lasers cover the entire wavelength range of CWDM systems (1271 nm to 1611 nm).

3.3 Application Issues Using Time Domain Based Return Loss Meters

3.3.1 OTDR (Backscatter Method)

For instruments based on OTDR technology, many methods are currently in use to measure the reflectance of a single reflective event. For measuring the reflectance of

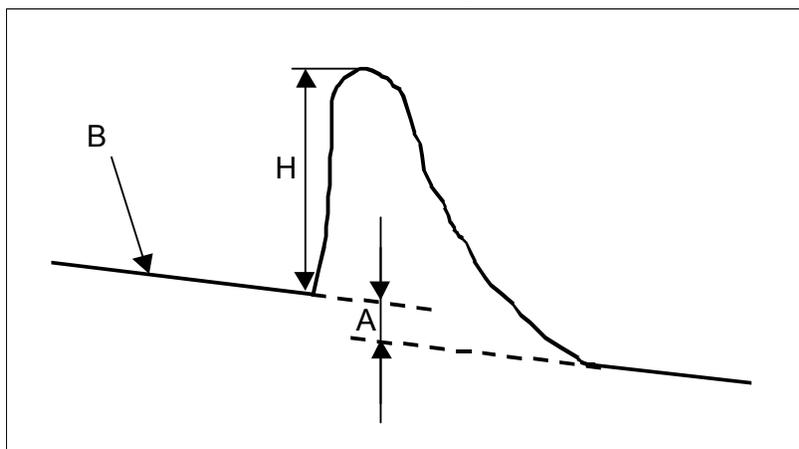


Figure 6: OTDR trace signature of a Fresnel reflection

point defects in a fiber optic network where the defects are not accessible, the reflectance is a function of the optical pulse length, the backscatter coefficient of the fiber, and the measured amplitude of the reflection above the backscatter level. Variations in the fiber's backscatter coefficient can lead to measurement errors. A calculation of the uncertainty associated with the backscatter level

measurement (within 95% confidence interval) of commercial SMF (Single Mode Fiber) results in 0.86dB (see Annex 1). This uncertainty increases in significance as the measured value of H decreases. Figure 6 shows the OTDR signature of a reflective event (Fresnel reflection). The potential measurement error increases for small magnitudes of H (power levels closer to the backscattering level B). To minimize the possible error one can increase H by choosing a shorter pulse (smaller pulse width) as long as the shorter pulse-width still yields ample measurement range. The measurement error resulting from the uncertainty in fiber backscattering level can also carry over to the insertion loss measurement A if the fibers used before and after the Fresnel event are not identical in their backscatter characteristic.

The user must optimize the image of the reflection on the display of the OTDR to make sure the detector is not saturated before making the reflection measurement. Saturated detectors will result in an increased error when measuring H . Choosing the proper pulse width to optimize the displayed image of the reflective event on the measurement screen can reduce measurement error. However, its effect on measurement range or event resolution might dominate the decision on which pulse width is most suitable for the application. While increasing the pulse lengths increases the OTDR's ability to measure long length of fiber, it reduces the OTDR's ability to detect reflective events with high return loss (low reflectivity) and reduces its ability to resolve closely spaced events.

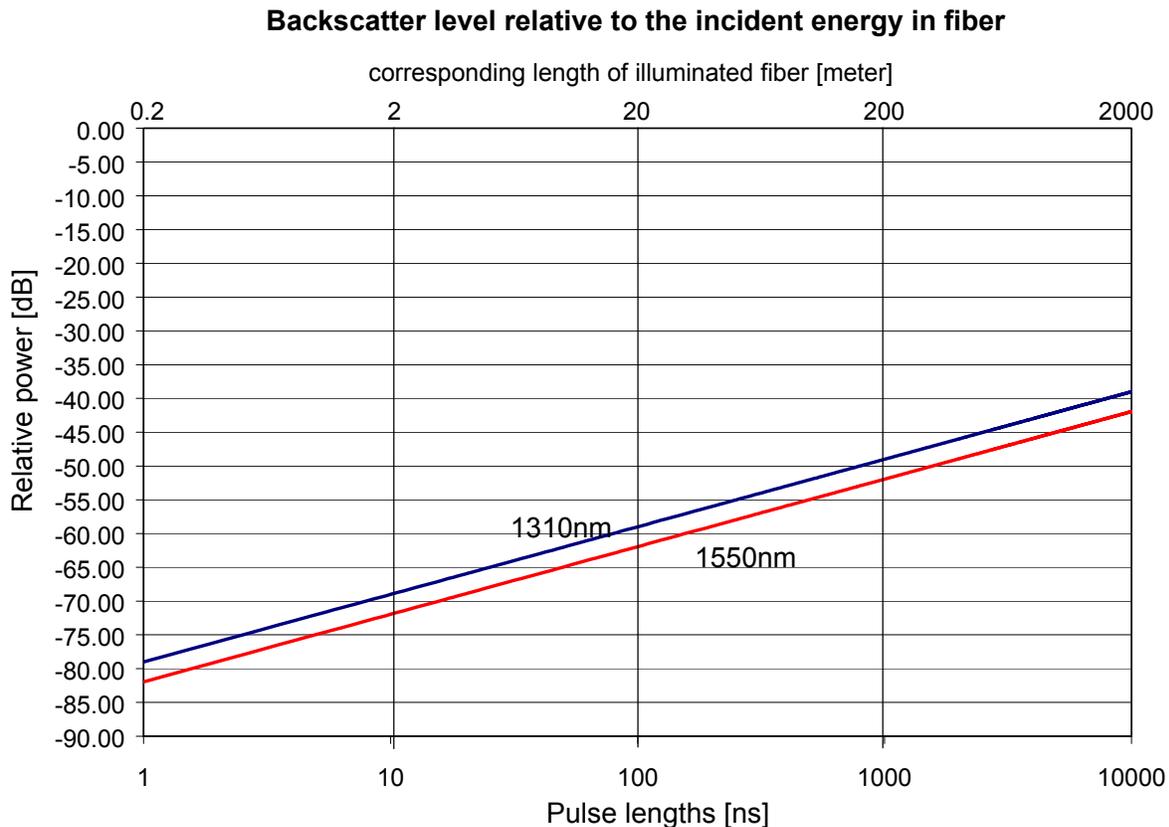


Figure 7: Backscatter Level as Function of OTDR Pulse Length in Singlemode Fiber

Figure 7 illustrates the fiber backscatter level as a function of OTDR pulse lengths (shown for 1310 nm and 1550 nm). The graph shows that if, for example, a 1000 ns (1 μ s) pulse length is used (at 1310 nm) reflective events with return loss in excess of ≈ 48 dB cannot be measured (graph shown for standard single-mode fiber, $n \approx 1.5$).

Just as increasing the pulse width increases the OTDR's ability to measure long lengths of fiber, it reduces the OTDR's event resolution or ability to distinguish between closely spaced events. For example, for a 100ns long optical pulse illuminating 20 meters of fiber only one reflective event can be accurately measured within that span. If more than one reflective event falls within the 20-meter span, the OTDR measures the combined reflected energy or combined insertion loss of both events. In this case a shorter pulse length should be used to measure the reflectance of each event separately. If the two reflective events are spaced closer than the resolution of the OTDR, a continuous wave return loss meter should be used to accurately measure the combined optical return loss.

Alternatively, a high resolution OTDR (other names are Direct Detection OTDR or Photon Counting OTDR) can be used if increased measurement resolution is needed.

These instruments offer ultra-short pulse lengths in the pico-second range and can accurately measure the reflectance of events spaced as close as 5cm to 10cm. These instruments often use photon-counting technology to achieve a >90dB measurement range. High detector sensitivity and long averaging coupled with high peak-pulse-power output signals allow the detection of backscatter signal levels caused by ps-long pulses. Visualizing the extension of Fig. 5, launching a 100ps long optical pulse at 1550nm, for example, causes the backscattered signal level to be 92dB lower than the transmitted signal level. High resolution OTDRs are used in the installation and maintenance of short-span optical networks as found, for example, in aircraft, space vehicles and satellites, or automobiles. OEMs and manufacturers of optical components can use high resolution OTDRs for production and troubleshooting. Figure 8 shows the trace signature of an EDFA (Erbium Doped Fiber Amplifier). This trace is taken with a Photon Counting OTDR that incorporates a 10cm event resolution. The various elements can be identified knowing the internal construction and design of the amplifier.

If the magnitude of individual reflections are measured using a reference reflection, test conditions like such as window size, adjusted sensitivity, and the selected number of averages must be kept constant between the reference measurement and the reflectance measurement. This procedure, often carried out manually, does allow for user error.

Other applications for high resolution OTDRs include precise distance measurements needed in optical sensors, such as fiber optic gyroscopes, or real-time monitoring of short span networks during operation. High resolution OTDRs are also available as wavelength tunable instruments. This allows a reflectance measurement versus wavelength and distance simultaneously, which can be particularly important for wavelength sensitive optical components used in DWDM systems.

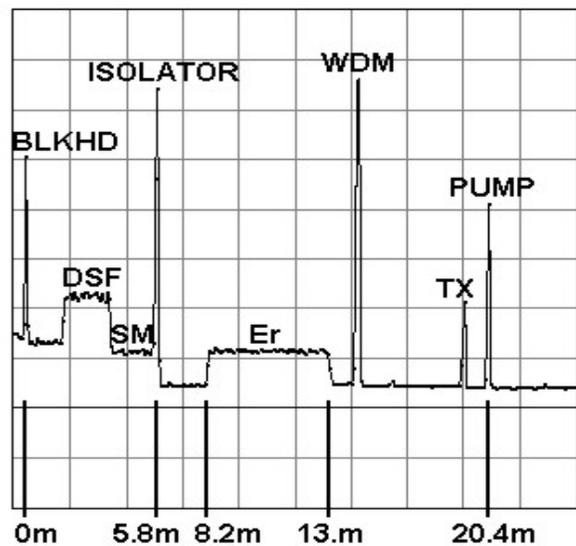


Figure 8: Trace Signature of EDFA Taken with Photon Counting OTDR

When the measurement application requires resolving reflections to the millimeter and even sub-millimeter level, a precision reflectometer can be used. This instrument is not an OTDR but shall be briefly discussed for completeness since it is used to measure return loss (reflectance). Precision reflectometers are based on a Michelson interferometer and utilize the technique of “white light” interferometry. A low coherence optical signal is split into two paths where one is sent to the device under test and the other one to a movable reference mirror. Recombining the light reflected from the DUT and the mirror results in a coherent interference signal when the path lengths are the same. The instrument can scan a device and display all reflections found by moving the mirror. The total measurement range is typically less than one meter. This technique is often used during the design of optical components. For example, it can be used during

the design or for troubleshooting of optical isolators. The reflections from the various elements of the isolator can be quantified and their contribution to the overall optical return loss of the isolator can be evaluated even though the isolator may only be a few centimeters long.

Installers of fiber optic cable verify physical characteristics of the installed cable plant using an OTDR. A trace analysis is typically performed on all fibers. The following picture shows an example of the OTDR trace of a fiber optic span where the OTDR is connected directly to the connector at the input patch panel.

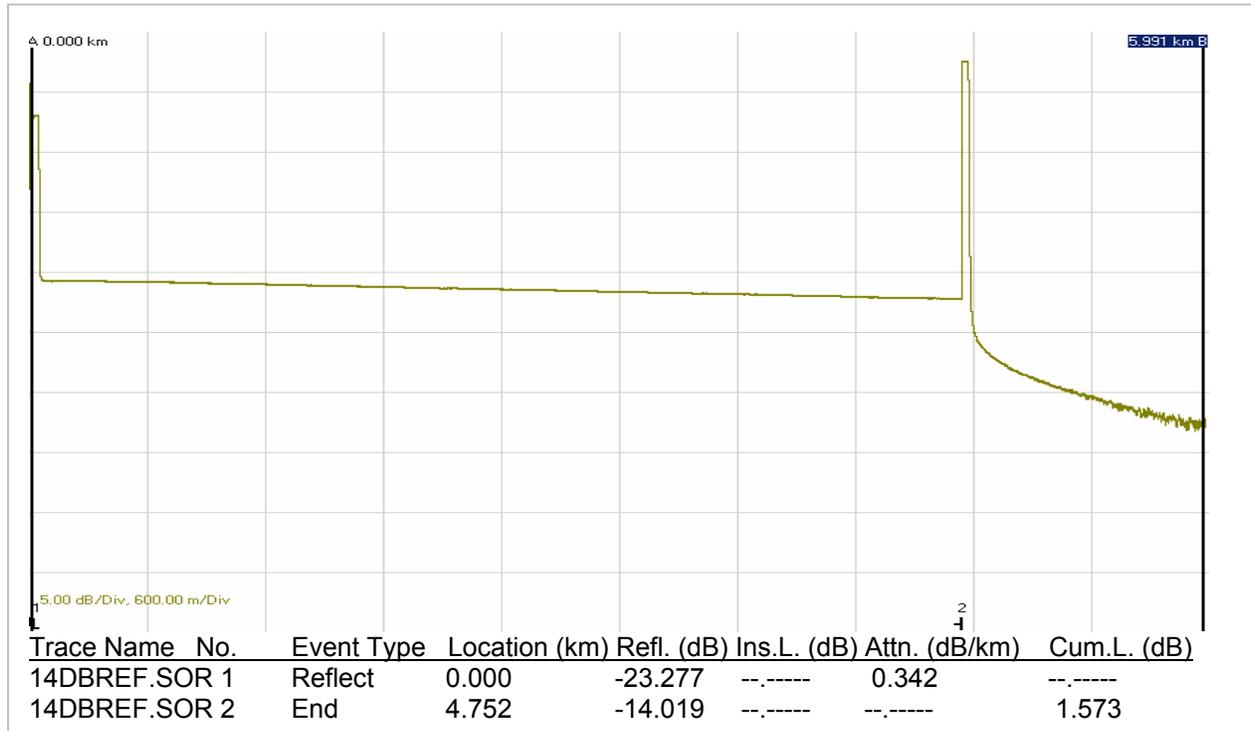


Figure 9: OTDR Trace Signature of 4.75km Span (No Deadzone Box & Terminator)

The connector at the input patch panel (location no 1) shows a return loss of 23.28 dB. The connector at the output patch panel (location no 2) shows a return loss of 14 dB. These return loss values do not reflect the actual physical condition of these connectors. The input connector is located too close to the OTDR and falls within its dead-zone. The connector at the output patch panel is not optically terminated (open) and exhibits a strong reflection due to the glass-to-air refractive index mismatch.

A dead-zone box and an optical terminator can be used to measure the return loss at the input and output patch panel. The dead-zone box (A) contains a length of optical fiber (B) and is connected between the OTDR and the input patch panel connector. The optical terminator is connected to the output patch panel connector and matches (C) its refractive index and optical properties.

A) EIA/TIA-455-59, 60, and 61 refer to a dead-zone fiber where in the field a dead-zone box (incorporating a length of fiber) would be used. The terms dead-zone fiber and dead-zone box are being used.

B) Above fiber optic test procedures suggest the length of the dead-zone fiber may be up to 20 times the OTDR pulse length, depending upon the characteristics of the OTDR. The OTDR pulse length in meters is approximately one-tenth the pulse duration in nanoseconds.

C) The terminator shall match the optical and physical properties (fiber type and size) of the cable plant under test including the polish type (e.g. flat, PC, SPC, UPC, APC) and return loss of the end connector. Since there are no specific industry standards defining required return loss values for these polishing types, the personnel conducting the test should verify company specific specifications governing the installed cable plant when selecting the optical terminator type.

Figure 10 below shows the trace from the same fiber optic cable plant as above but now with a dead-zone box installed between the input patch panel connector and the OTDR and a fiber optic terminator installed at the output patch panel connector.

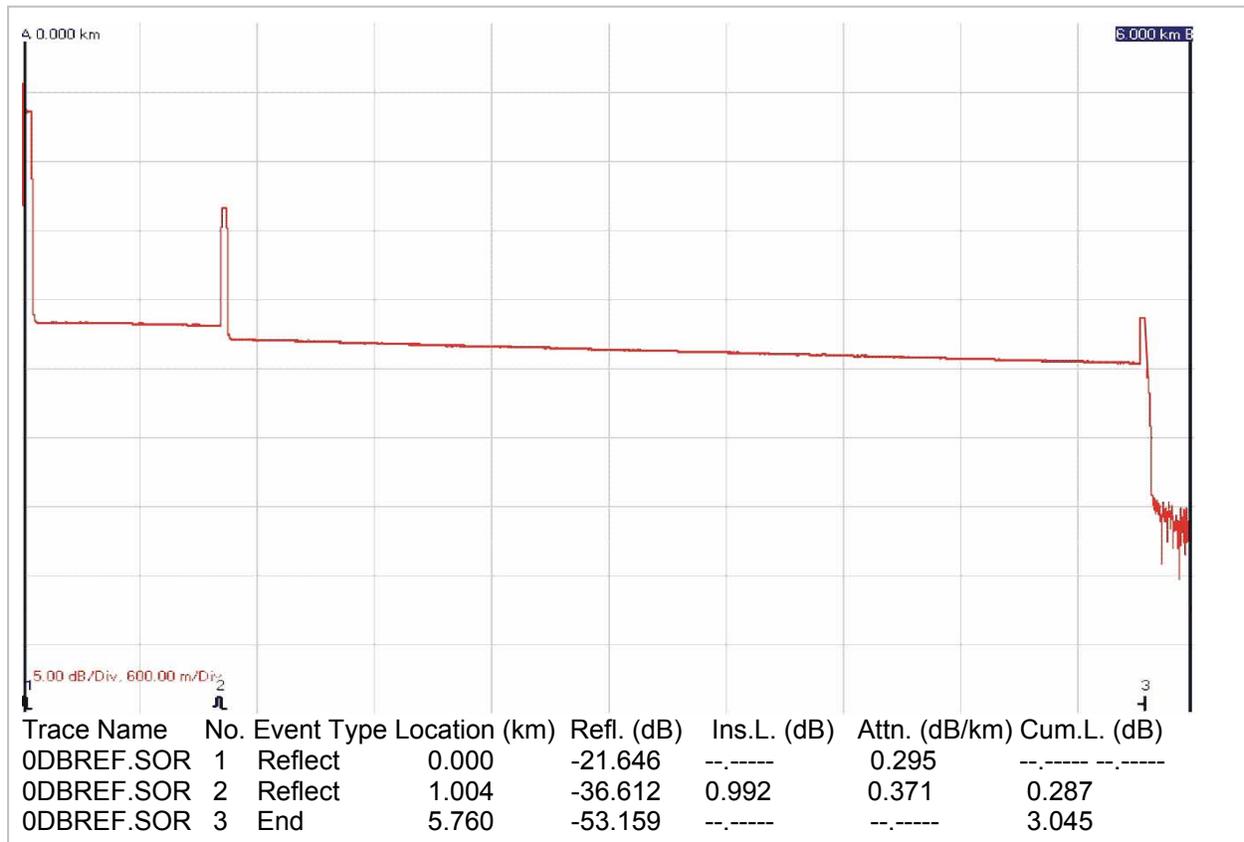


Figure 10: OTDR Trace Signature of 4.75km Span (w. Deadzone Box & Terminator)

The dead-zone box contains 1km length of fiber. The reflection at the input patch panel is now recorded as location no 2 and measured with 36.61 dB. The reflection at the output patch panel (location no 3) is now optically terminated and measured with 53.16 dB. Note that the length of the dead-zone fiber has to be subtracted from the measured distances since the dead-zone fiber is not a permanent part of the installed cable plant.

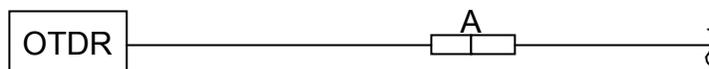
3.3.2 OTDR (Reflective Event Comparison Method)

Instruments using this method are often used in facilities that manufacture fiber optic components and are particularly well suited for connectors. Here the reflectance of the components must be verified and monitored to ensure, and provide proof of, a sufficient quality product. Throughput (short testing time) is crucial. Typically both input and output of the component are accessible and the test procedure must not contain any practices that would damage or alter the component under test.

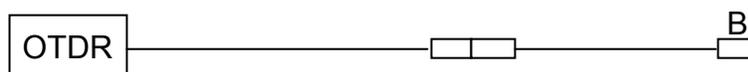
The test specimen often has short cable lengths. This method also finds applications where the event dead zone of traditional network OTDRs exceeds the distance between two reflective events that need to be measured independently (spatial resolution is critical). Instruments that use the Reflective Event Comparison Method are not capable of measuring ORL in the defined sense. This means they can not measure the accumulated return loss of an entire span. The measurement result is always associated with a specific reflection under test.

If the reflective event that is to be evaluated can be separated (de-mated) or an optical connection is available shortly before or after the event under test, an OTDR using the Reflective Event Comparison Method can be used as shown in the following situations:

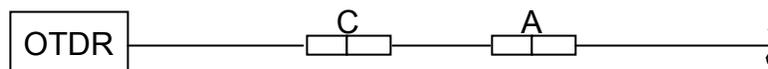
(Method 1) The joint at the reflective event A can be separated. The unmated connector at A must exhibit a 4% reflection unless the OTDR uses a calibrated internal reflection.



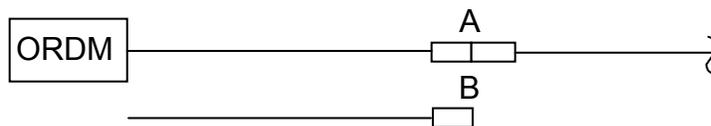
(Method 2) The joint at the reflective event A can not be separated. A 4% reflective event must exist beyond the joint A at location B unless the OTDR uses a calibrated internal reflection.



(Method 3) The joint at the reflective event A can not be separated. A 4% reflective event C must exist in front of the joint A unless the OTDR uses a calibrated internal reflection.



(Method 4) The reference at location B can be provided by a second fiber of similar distance from the test instrument in order to measure the reflected power at A.



Depending on the test conditions and the particular method used to measure the reflected power from an event as shown in the examples above the test results tend to be more or less accurate. The following table summarizes reflectance measurements performed on a three patch cord single-mode cable configuration (all patch cords are 5m lengths). The four situations from above were applied to demonstrate the possible magnitude of fluctuation between test results.

Method	1	2	3	4
Measured reflectance for DUT at location A	-51.53 dB	-50.48 dB	-52.07 dB	-51.87 dB

Table 4. Measurements on Cables Using Reflective Event Comparison Method

The amount of variation between the reflectance results above depends on the individual connector losses and cable lengths in between the reflective events A, B, and C. For 5-meter patch cables the reflectance measurements shown are reasonably close. The measurement uncertainty resulting from above 4 methods can possibly be reduced by measuring the absolute power at the reference location with an additional power meter. The differences in absolute power can then be taken into account.

Advantages:

- Short testing time
- No mandrel wrap necessary for reflectance measurements (compared to OCWR) unless the fiber length is shorter than the minimum length specified by the instrument manufacturer (typically 1.5 to 2 meters)
- The two event deadzone is shorter than those of network OTDRs
- Less prone to operator error
- Less fiber manipulation
- Generally more repeatable and reproducible measurements (compared to OCWR)

Disadvantages:

- Does not measure cumulative reflected power from multiple reflections.
- The DUT must be accessible (no remote fiber testing).

4 Calibration Issues and Industry Status

Next to optical power meters (used to measure absolute optical power and attenuation) return loss meters might be the next popular category of optical test and measurement equipment. Unlike optical power meters, there are no industry recognized calibration standards or return loss calibration artifacts available from NIST (National Institute of Standards and Technology). There is also no calibration service available for Return Loss Meters from NIST or any other government recognized agency. There has been a long existing concern among industry users regarding the repeatability and reproducibility of RL measurements based on different techniques as well as among different manufacturers' products. Considering the preceding comments, it is just normal to observe measurement variations of $\pm 1\text{dB}$ and even $\pm 2\text{dB}$ for reflectance measurements using the same technique but different set-ups (much more so when comparing different techniques). Further, there appears to be little standardization in the definition of relevant return loss meter performance parameters among manufacturers. For example, a significant performance parameter is a return loss meter's measurement range, the quantification of its ability to measure Return Loss. Manufacturers of Return Loss Meters might use 1) Dynamic Range, 2) Detector Sensitivity, or 3) Measurement Range to state their products ability to measure Return Loss and depending on the manufacturer's interpretation of the term, can mean something different.

These basic concerns are aggravated as return loss measurement requirements have crept up to higher and higher levels, from the nominal "Super PC" level of 40dB (around 1995) to the 65+dB requirements of "Ultra PC and APC" levels today (in 2001). The shift from single wavelength to DWDM transmission systems has also driven the concern for accurate return loss versus wavelength measurements.

These issues have recently come to the attention of the major fiber optics standards bodies. As IEC TC86 WG4 is chartered to address calibration issues in support of fiber optic test and measurement, a new work program is just being initiated on the calibration of return loss meters. The strategy to develop this reference document will probably need to encompass a number of industry-wide support activities:

- Develop return loss SRM (Standard Reference Material).
- A first-round robin to establish the reproducibility of different techniques, and instruments versus various return loss levels.
- If necessary, a second round robin to demonstrate refinement in the techniques and reference standards.
- Develop and release formal IEC document titled Calibration of Return Loss Meters.

A need exists further to harmonize the specifications of instruments that can be used to measure return loss. E.g., typical specifications for OTDRs do not include “return loss measurement range” or “reflectance measurement range”. When it comes to measuring reflectance and return loss, OTDRs and OCWRs do not share the same specified parameters. This makes it difficult to select the correct equipment if in a given case the primary intent of the instrument is to conduct reflectance and return loss measurements.

Recommendation for terminology to be further defined where applicable:

- ORL Measurement Range
- Reflectance Measurement Range

Figure 11 illustrates a possible calibration/performance verification setup that can be used to verify the accuracy of a return loss meter and its linearity. The absolute accuracy of the return loss meter can be verified using a calibrated reflection standard. Often glass to air terminations with 4 % reflectivity, approximately 14 dB return loss are used. However, variations in the fiber’s refractive index, the end-face polish, and the end-face cleanliness can contribute to a measurement error. Using a fixed or variable attenuator and applying a highly reflective coating (mirror) to the fiber end-face can offer a more precise alternative. The effective return loss of the setup in Figure 11 is:

$$RL = 2 \cdot a_{tot} + R \quad [dB]$$

R represents the known reflectance terminating the fiber end and a_{tot} the attenuation of the optical attenuator. The fiber length between the instrument and the temporary joint (TJ) shall be long enough to overcome deadzone requirements if time domain based instruments are being verified. The fiber length between the temporary joint and the end of the fiber shall be short to eliminate the effect of the backscattering level of the fiber.

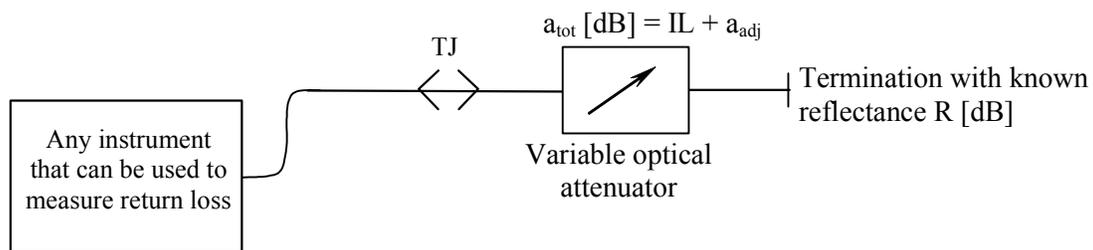


Figure 11: Generic Calibration Set-up for Return Loss Meters

The accuracy of an instrument calibrated with the above measurement depends on:

- The accuracy of the reflectance R

- The accuracy to which the insertion loss of the attenuator a_{tot} is known at any position through the attenuation range
- The accuracy to which the insertion loss of the temporary joint (TJ) can be reproduced when replacing the calibration setup with a test device.
- The polarization dependence of the attenuator and calibration setup
- The return loss of the attenuator itself (only an issue for OCWR)

4.1 Reference Cables / Reference Jumpers

When the reflectance of individual connectors is measured, the test result applies to the mated pair. One part of the mated pair is the reference cable or reference jumper. To guarantee repeatability of measurement results regardless of date, time, operator, test equipment manufacturer, type of instrument, etc., the reference cable or reference jumper must be manufactured to strict quality standards.

1) For the cable assembly manufacturer and those who purchase cable assemblies, the purpose of using high quality reference jumpers is to guarantee that test results for a given cable assembly, performed by one company, can be reproduced when tested by another company.

2) For the end-user of cable assemblies it may be desirable to know what the return loss and insertion loss of purchased cable assemblies is once they are installed in the field to verify that their actual performance meets the system design requirements. A "random mate test" can provide that information. Here, cable assemblies are randomly mated and tested against each other. These test results may differ from the cable assembly manufacturer's test results because the physical condition of the mated pair is different. Here cable assemblies are mated to each other rather than to the high quality reference cable or reference jumper. The measurement difference depends on the grade of the purchased cable assembly. Cable assemblies manufactured to a lower standard will give a higher variability.

The above are two different tests with two different objectives. The cable assembly manufacturer is responsible for accuracy and reproducibility of the measurements when tested against a known standard. The end-user is responsible for making sure the product meets the requirements within the given application.

For example, a connector might exhibit a reflectivity of better than -50dB when tested against a reference cable (reference jumper), but in average exhibits -45dB when mated to other cable assemblies tested to the same conditions.

5 References

5.1 Normative References

TIA/EIA-488-8, FOTP-8, Measurement of Splice or Connector Loss and Reflectance using an OTDR, 1998

TIA/EIA-488-107, FOTP-107, Determination of Component Reflectance, or Link/System Return Loss Using a Loss Test Set, TIA/EIA-455-107A, 1999

CEI/IEC 61300-3-6, Second Edition, Basic Test and Measurement Procedures – Part 3-6: Examination and Measurements – Return Loss, 2001

CEI/IEC 61746, Ed 1, Calibration of Optical Time- Domain Reflectometers, International Electrotechnical Commission, 1999

TR-TSY-001028, Generic Criteria for Optical Continuous Wave Reflectometers, Bellcore, Issue 1, 1990

TR-NWT-000196, Generic Requirements for Optical Time Domain Reflectometers, (OTDRs) Issue 3, 1993

5.2 Other References

D. Anderson, F. Bell, “Optical Time-Domain Reflectometry”, Oregon, Tektronix, Inc.

D. Derickson, “Hewlett-Packard Professional Books: Fiber Optic Test and Measurement”, New Jersey, Prentice Hall, pp. 383-472, 1998.

R. Buerli, “Measure Return Loss in Multimode Fiber Optic Systems”, Test & Measurement World, pp. 59-64, 2000.

Annex 1

Evaluation of the Backscatter coefficient uncertainty (B_{ns}) as a function of fiber parameters: numerical aperture (NA), index of refraction (n) and attenuation coefficient (α)

Assumed variations, as per Corning SMF-28 Specification Date Sheet, Corning Engineering Handbook (1994):

$$NA = 0.13 \pm 2.69 \% \quad \alpha_s = 0.25 \text{ dB/km} \pm 8.3 \% \quad n = 1.468 \pm 0.03 \%$$

$$NA := 0.13 \quad \alpha_s := 0.25 \quad n_1 := 1.468$$

$$u_{NA} := \frac{2.69}{100} \cdot NA \quad u_{\alpha_s} := \frac{8.3}{100} \cdot \alpha_s \quad u_{n1} := \frac{0.03}{100} \cdot n_1$$

$$B_{ns}(NA, n_1, \alpha_s) := 10 \cdot \log \left[\left(\frac{NA}{n_1} \right)^2 \cdot \frac{\alpha_s}{4.55} \cdot 0.0001 \right]$$

$$c_{BNA} := \frac{d}{dNA} B_{ns}(NA, n_1, \alpha_s) \quad c_{BNA} = 66.815$$

$$c_{Bn1} := \frac{d}{dn_1} B_{ns}(NA, n_1, \alpha_s) \quad c_{Bn1} = -5.917$$

$$c_{B\alpha_s} := \frac{d}{d\alpha_s} B_{ns}(NA, n_1, \alpha_s) \quad c_{B\alpha_s} = 17.372$$

$$u_B := \sqrt{(c_{BNA} \cdot u_{NA})^2 + (c_{Bn1} \cdot u_{n1})^2 + (c_{B\alpha_s} \cdot u_{\alpha_s})^2}$$

$$u_B = 0.43$$

$$U_B := 2 \cdot u_B \quad \text{Expanded uncertainty of Backscatter coefficient:}$$

$$U_B = 0.859 \quad \text{(dB) with a level of confidence of 95 \%}$$