Multi-Channel Return Loss Measurement

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Introduction

Demand by communications media providers for expanded bandwidth, brought about by factors such as the widespread implementation of digital communications and the booming popularity of the Internet, appears to compound almost daily. The ability to deliver larger amounts of information quickly, reliably, and conveniently has merely whetted the public's appetite for more, and has placed ever-increasing stress on the components comprising the Information Superhighway.

The fiber optic backbone that forms the spinal cord of the Information Superhighway, and its numerous and diverse components, have not been excluded from this demand for higher performance.

Years ago, the only measurement of importance to those testing the performance of optical components and optical trunks was insertion loss—essentially the leakage of light energy due to fiber misalignment and other factors. Today, esoteric measurements such as polarization dependent loss, return loss, and other formerly obscure performance parameters, are of paramount importance to anyone working in the field of fiber optic communications.

Each of the aforementioned parameters, if not carefully qualified, is likely to impair the performance of a fiber optic system and will ultimately reduce the transmission capacity of the network. Insertion loss introduced by optical components affects the loss budget of the system. Polarization dependence causes polarization mode dispersion, which degrades the transmission speed of the network. Finally, reflections caused by system components can shift the operating wavelength of a transmitter and introduce noise. This is known as return loss.

Reflections, and the resulting return loss noise, are associated with many fiber optic components including connectors, switches, couplers, and attenuators. In most cases these components are individually qualified.

To make the laborious process of measuring insertion loss and return loss (reflectivity) more efficient, a number of automated systems have been designed that allow the testing of multiple devices. This article will review the different methods devised for measuring return loss and how they affect the testing and qualification of multi-channel systems.

Defining Return Loss

Reflection, Reflectance, Return Loss

Reflections—or more specifically Fresnel reflections—in the field of fiber optics occur at the boundary between two media with different refractive indices. The percentage of the light reflected can be calculated with knowledge of the refractive indices of both media, n1 and n2:

$$\text{Reflection Factor} = r^2 = \frac{(n1-n2)^2}{(n1+n2)^2}$$

The most commonly known percentage of reflected power, the 4% reflection, is caused by a glass to air boundary. Such a reflection occurs at any Physical Contact (PC) connector that is left open to the air.

Reflectance, in general, is the ratio of reflected power to incident power. When knowledge of a reflection at a discrete point is important, the term reflectance is preferred. Reflectance is expressed in negative decibels (dB):

$$\text{Reflectance} = 10 \log \frac{P_{Refl}}{P_{Inc}} = 10 \log (r^2)$$

Optical Return Loss (ORL), often referred to simply as return loss, describes the ratio of reflected power over the incident power of a system as a whole.

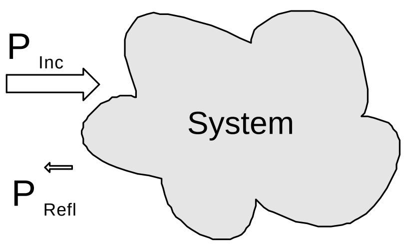
Similar in concept to reflectance, return loss is expressed in decibels (dB), and may be calculated as follows:

$$\text{Return Loss} = \text{ORL} = 10 \log \frac{P_{Inc}}{P_{Refl}}$$

The basic method to measure reflectance or return loss is to launch a known power level of light energy into a system or component and find some means of measuring the reflected power.

System Return Loss

If the all the reflected power of a system is related



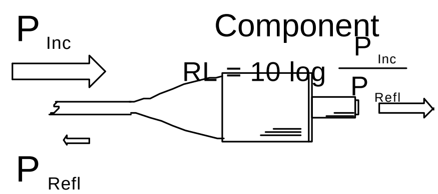
to the launched power, we refer to it as the system

$$RL = 10 \log \frac{P_{Inc}}{P_{Refl}}$$

return loss. Certain return loss measurement schemes, such as the continuous wave method, measure only the system return loss.

Component Return Loss

Measuring the return loss of a discrete component, such as an in-line attenuator, is important for the qualification of that particular device. Measurement methods based on a reflectometer principle are geared toward resolving the issue of component return loss, or under some circumstances, the reflectivity of individual media transitions.



Return Loss Measurement Methods

Optical Continuous Wave Reflectometry Method

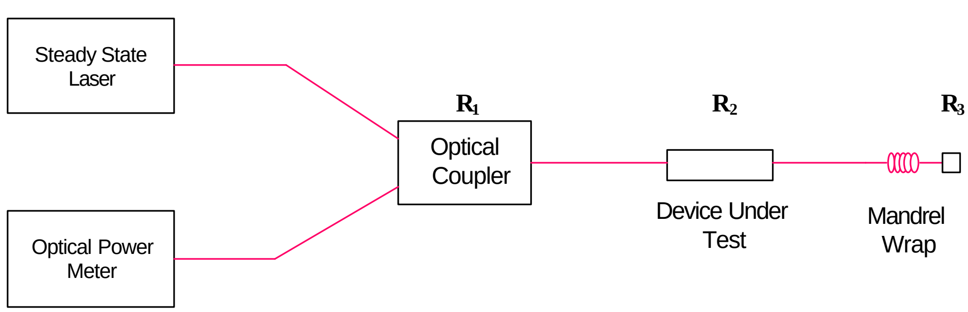


Fig.1, Return Loss Measurements using Optical Continuous Wave Reflectometry, OCWR

The most widely used method for return loss measurement is Optical Continuous Wave Reflectometry (OCWR). In this method, a continuous wavelength of light energy is passed through an interface, connector, or device under test. The returned power is then measured and the return loss calculated. Using only a calibrated light source, coupler and an optical power meter, return loss measurements using the OCWR method can be accomplished with accuracy. OCWR test procedures are described in detail in FOTP-107[1].

The absolute accuracy of an OCWR instrument depends on the insertion loss and reflectivity of the components in the return loss path such as the optical coupler, bulkheads, couplings, and patch cords. To perform accurate return loss measurements, two calibration steps are necessary:

1. Calibrate the instrument against a known reflection
2. Measure the background return loss

OCWR Calibration with a Reference Reflection

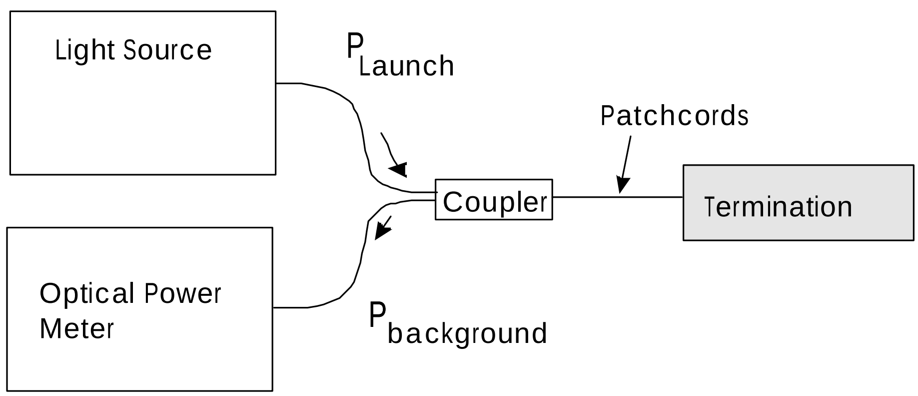


Figure 1 QCWR Calibration

A clean and polished PC-terminated connector left open to the air results in a very accurate 4% reflection. This is equivalent to a 14.7 dB return loss, if it is assumed that the refractive index of the fiber is 1.45. For other fiber types, use the formula for calculating the reflection factor given above.

To calibrate an OCWR instrument for absolute measurements, a PC terminated reference cable is connected. The reflected power level is then measured and logged as a reference. Subsequent measurements of devices under test are related to this absolute reference as follows:

$$RL_{DUT} = 14.7\text{ dB} + 10 * \log (P_{REF\ 4\%} / P_{Measured})$$

Background Reflection, Background Return Loss, and the OCWR Method

All components in a return loss measuring path contribute to the reflected power. This parasitic reflected power is known as background reflection. To measure components or systems with high return loss (low reflectance) using an OCWR setup, the background return loss, i.e., the reflected power level caused by components other than the device under test, must be determined beforehand and subtracted from the actual measurement.

Background return loss is measured without a device under test connected to the OCWR setup. The end of the fiber that connects the OCWR setup to the device under test must be properly terminated so that it eliminates all reflections that could affect the baseline measurement. This can be accomplished by using either a dedicated termination plug, a mandrel wrap (coiling the fiber several times around a hexagonal rod) or through the application of index matching oil or gel at the end of the fiber.

$$\text{Background RL} = 10 * \log (P_{background} / P_{incident})$$

After logging the background reflected power of the OCWR setup, the subsequent measurement of the device under test can be corrected for background return loss as follows:

$$P_{RL\ DUT} = P_{measured} - P_{background}$$

Thus, the actual return loss of the device under test is calculated as:

$$RL_{DUT} = 14.7\ dB + 10 * \log (P_{REF\ 4\%} / P_{RL\ DUT})$$

Assuming that the launched power is stable within 0.1 dB, return loss measurements can be performed within the accuracy range of the optical power meter.

Optical Time Domain Reflectometer Method

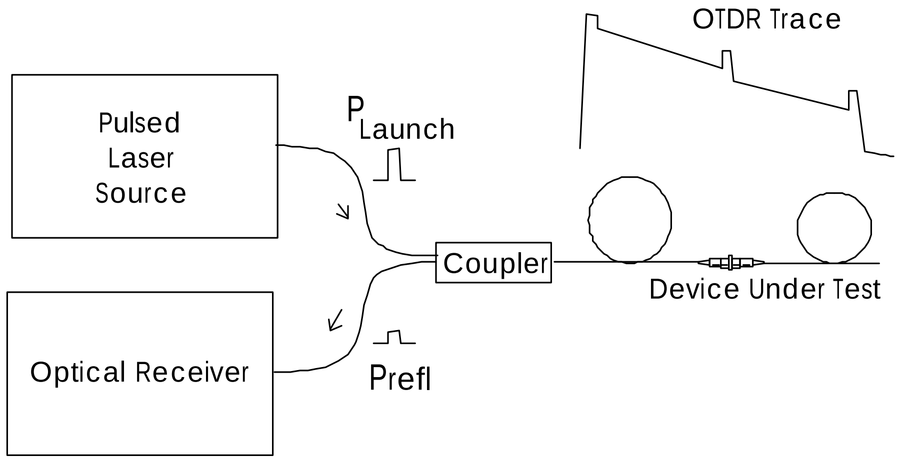


Figure 2 OTDR Method

The Optical Time Domain Reflectometer launches light pulses into the device under test and collects backscatter information as well as superimposed Fresnel reflections. The OTDR is optimized to accurately measure loss-per-distance based on the received backscatter level. An OTDR also gives an estimation of the strength of a reflection at a given distance based on its peak height.

Calibration of the OTDR

Like the OCWR instrument, the OTDR can be calibrated using an open PC termination. Since an OTDR is tuned to measure backscatter signals, which requires much greater sensitivity, such a calibration is not always possible. Typically, the strong 4% reflection will saturate the OTDR amplifier and make such a measurement impossible. A more common method is calibrate the OTDR to a known level of backscatter signal and then calculate the reflection peak in relation to it. Such a calibration is usually conducted by the manufacturer of the instrument, and the calculation of the return loss is accomplished by embedded software in the instrument.

Optical Reflection Discrimination Method

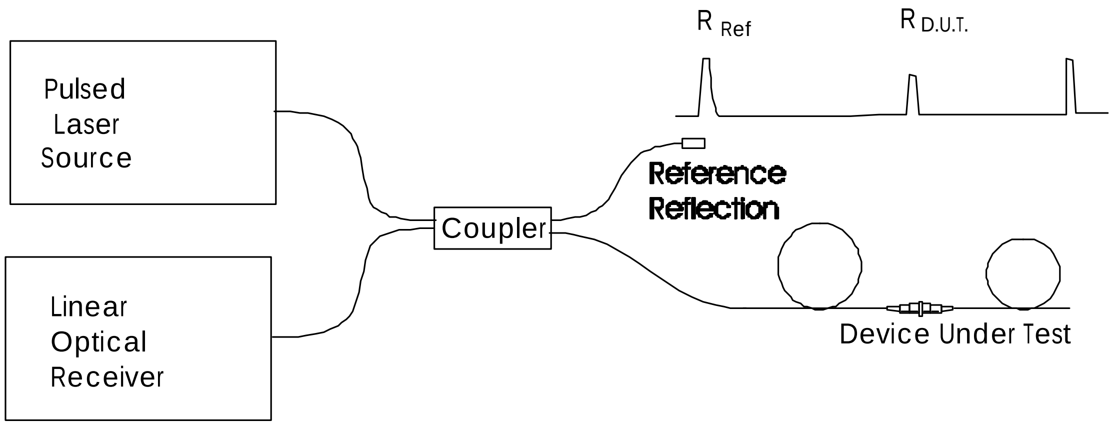


Figure 3

The Optical Reflection Discrimination instrument is based on the optical reflectometer method. Much like the OTDR, the ORD instrument launches a train of pulses. The reflected pulses are guided through the coupler to the optical receiver, amplified, and then sampled. A time discrimination process allows the setup to isolate and quantify individual reflections. Since the optical receiver is highly linear, the amplitude of the reflections are directly proportional to the reflectivity, and thus the return loss. Whereas the conventional OTDR is optimized to measure backscatter signal, the ORD instrument is optimized to measure reflections.

Calibration of an ORD Instrument

Like the OCWR based instruments, the ORD instrument can be calibrated using an open PC connector that causes a 4% reflection. It is also feasible to actually build the reference reflection into the ORD instrument by terminating the fourth port of the coupler with a PC-polished connector (see figure). This built-in reference reflection will eliminate one step in the reference and calibration procedure.

ORD, OTDRs and Background Reflections

Both the ORD instrument and the OTDR discriminate reflections against elapsed time. Neither instrument registers background reflections. This lack of sensitivity to background reflections is an advantage when conducting multi-channel measurements. Optical components in the measuring path, such as couplers and switches, do not influence the measurement.

Multi Channel Measurement

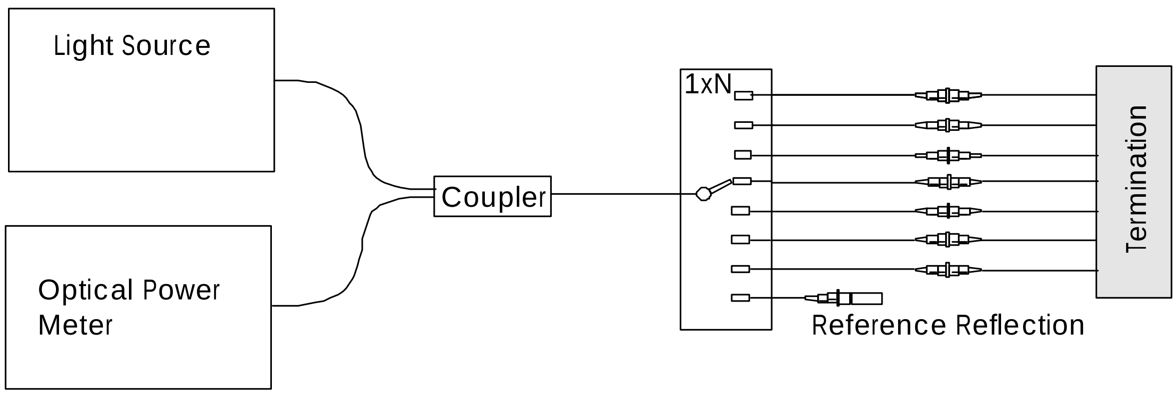


Figure 4

When measuring insertion loss and return loss on many devices simultaneously, an obvious approach is to simply install multiple computer controlled single component instruments in a single cabinet. This approach offers a very efficient way of acquiring the necessary component parameters. Unfortunately, it is also the most costly.

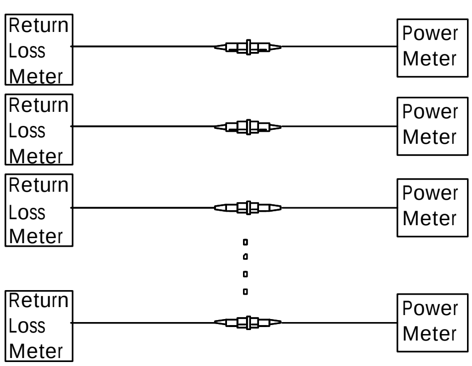


Figure 5

Optical switches are components often used to conveniently multiplex light sources, return loss meters and power meters. Two popular methods devised to perform accurate multi-channel insertion loss measurements rely on optical switches.

In the first, considered the most accurate method, a switch multiplexes the light energy from a single source to each channel. The power level is then measured by an individual power meter dedicated to each channel. The absolute reference power, as well as the insertion loss, is measured directly from the endface of the devices under test.

In the second method, a single light source and a single optical power meter are multiplexed using two optical switches. To eliminate inaccuracies caused by differences in individual connectors, i.e., connector repeatability, the devices under test must be spliced in-line after the reference power measurement has been taken. This method assumes that the splices do not add significantly to the insertion loss. Known as the cutback method, it is described in detail in GR-326-CORE [2].

Optical switches are also used to multiplex the measuring path when conducting return loss measurements. One advantage of a switched return loss setup is that one channel can be connected to a known reference reflection.

When measuring multi-channel return loss using a switched setup, careful consideration must be given to the following:

1. In most cases, the far ends of the devices under test must be terminated in a manner similar to a conventional unswitched setup. The terminations can only be eliminated if the reflections caused by the components beyond the devices under test are on the same order of magnitude, or smaller, than the reflections of the tested

devices. Reflections caused by the far end of the setup also add to the background return loss of the system. Termination of the far ends of the devices under test will preclude concurrent insertion loss measurements of the optical paths, unless angle-polished connectors (APC), in conjunction with an anti-reflective coating on the power meter detector surfaces, are used.

2. Additional components in the measuring path, such as the optical switch, connector interfaces, and patchcords, will add reflections and increase the inherent reflected power and, thus, background return loss. A higher background return loss reduces accuracy when the return loss of the measurement path is already high, and may even limit the dynamic range of the test setup.

   An ideal multi-channel return loss test setup uses optical switches with high return loss (> 60 dB) and fusion splices or angled polished connectors (APC) on all patch cords.

3. Additional components in the measuring path will add to the insertion loss. For any insertion loss measurement—specifically if the cutback method is applied—the added insertion loss must be accounted for.

   The return loss measurement, therefore, must be corrected as follows:

$$RL_{actual} = RL_{measured} - 2 * IL_{path}$$

where IL_{path} is the additional insertion loss caused by the measuring path, the loss of the switch and all connections. For each channel the insertion loss IL_{path} must be measured and logged.

4. The fiber itself causes return loss due to back scattering. Particularly for longer cable runs in the 10's of meters, the length of fiber installed between the return loss meter, optical switch, environmental chamber, and other devices will add to the background return loss. [3]

To achieve accurate and precise measurements, the multi-channel configuration must be designed and its components specified carefully. During installation, or after each reconfiguration, each channel must be carefully calibrated. This results in extremely long setup times. A software-guided calibration and referencing procedure is a welcome time saver. Such software guides the operator through the calibration and automatically logs the reference data.

OCWR-based Multi-Channel Setup

When specifying a multi-channel insertion loss and return loss measurement system based on the OCWR method, high grade optical components are called for. Special care must be taken where the light path meets the detector. For accurate measurement of the return loss, a proper termination of the far end of the device under test is also essential.

For automated measurements a mandrel wrap is impractical. Depending on the device under test and the parameters to be measured, for instance absolute insertion loss, the OCWR method is not feasible.

OTDR or ORD-based Multi-Channel setup

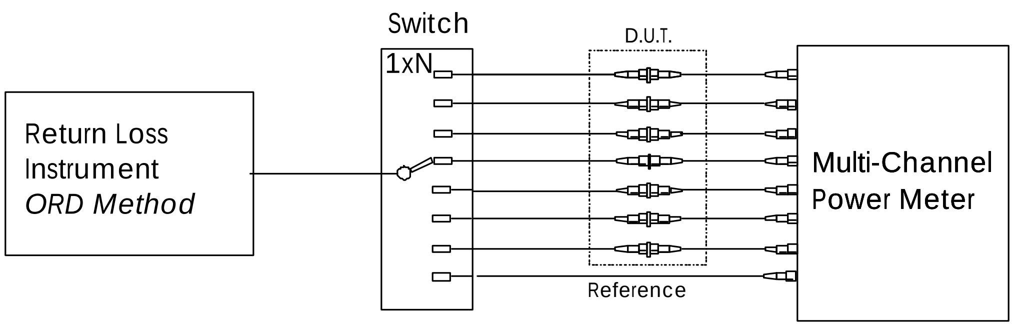


Figure 6

For accurate insertion and return loss measurements on short cable runs, as found in multi-channel setups, the OTDR is not a preferred method. However, the ORD instrument is specifically designed for such multi-channel measurements.

Like the OCWR instrument, the ORD contains a stable laser source for the insertion loss measurement. The absolute power level is referenced for each channel before the devices under test are inserted. For long term testing, a dedicated reference channel monitors the stability of the light source.

The ORD method permits isolation of the reflections caused by the devices under test from all other reflections in the measurement path. This has the following advantages:

a) No termination is needed at the far end of the devices under test,

b) background reflections do not affect the measurement accuracy or range. This eliminates the need for high grade optical components, and specifically relaxes the performance requirements of the switch.

Summary

Multi-channel systems can be implemented with the conventional OCWR method, by using an OTDR, or by selecting an ORD-based instrument. Using optical switches, either the sources, the power meters, or both, are multiplexed in all methods. With these additional components, and others, in the measurement path, parasitic reflections and additional losses must be accounted for. This is achieved by referencing each channel to compensate for additional insertion loss which will otherwise distort the return loss measurement. A reference reflector connected to a dedicated channel can be used as a global reference for the return loss measurements. A software-guided referencing procedure is essential for calibration and the accurate and efficient operation of the system.

Each of the methods of return loss measurement has its limitations. The advantage of the ORD method is that reflections are directly measured by sampling the reflections from the device under

test, without being contaminated by background return loss. The measurement capability is not limited by cable length, the grade of the optical switch, or the termination of the cabling. A multi-channel return loss setup based on Optical Reflection Discrimination, coupled with application software that guides the user through the calibration process, and logs and processes the data acquired, is a better choice for component qualification, cable testing, and DWDM system testing.

[1] Return Loss for Fiber Optics Components, FOTP-107, EIA/TIA
[2] Generic Requirements for Single Mode Optical Connectors and Jumper Assemblies, GR-326-CORE, Bellcore
[3] Return Loss Measurement Techniques for Installed Optical Fiber Links Telecom. Journal of Australia, Vol.42, No2, 1992