Abstract

This application note describes return loss measurement based on optical continuous wave technology. The principles of return loss measurement are discussed. In addition, the practical usage of the Keysight Technologies, Inc. 8161X Return Loss modules is explained for various use cases.
Introduction

Optical reflections can seriously degrade system performance and measurement accuracy. Here, we study reflections and optical interference, and discuss return loss techniques. The motivations for these measurements are listed in figure 1.

Return Loss Testing
Why is it necessary?

- Single reflections can cause source instabilities (power and wavelength) in non-isolated laser sources.
- Multiple reflections cause optical interference.
  In the "coherent" case, the total reflection depends on the source wavelength.
  In the "incoherent" case, the total reflection does not depend on the wavelength.
  Additional baseband noise is created in this case.
  This reduces the signal-to-noise ratio and increases the bit error rate.

Figure 1: Reasons for Return Loss Testing

When the system or measurement setup contains more than one reflection point, two idealized cases can be distinguished: the “coherent” case and the “incoherent” case.

Multiple Reflections - the "Coherent" Case -

The coherence length of the source is longer than 2 × the cavity lengths.

\[ \phi_1 = \sqrt{\phi_1^2 + \phi_2^2} \]

For two reflections, the total reflection varies sinusoidally with wavelength.

For multiple reflections, the wavelength dependence of the total reflection contains several sine waves.

The largest reflection is:

\[ \phi_{total} = \frac{\phi_1 + \phi_2}{2} \]

Optical power reflection

\[ \phi_{field} = \frac{\phi_{total}}{2} \]

Electrical field reflection

Polarization alignment is assumed!

Figure 2: Coherent superposition of multiple reflections

To demonstrate the wavelength dependence, an example with two reflections was calculated, as shown in figure 3. Each reflection is 4 %, and the spacing between them is 1 mm. In this case, the power reflection oscillates with 16 % amplitude. The individual peaks are separated by the free spectral range (FSR) of approximately 1.2 nm; the term “free spectral range” comes from the theory of Fabry–Perot resonators. It is obvious that Fabry–Perot resonances between closely-spaced reflection points can cause large uncertainties in measurement setups.

Figure 3: Calculated wavelength dependence of a cavity with an FSR of 1.2 nm.

When the spacing between the reflection points is much wider than the coherence length of the source, the situation is incoherent, as shown in figure 4. The power reflections add up with no dependence on the wavelength, and the transmission is reduced by the accumulated power reflections. This represents the best case for optical power and insertion loss measurements.

Figure 4: Incoherent superposition of multiple reflections

The setup illustrated in figure 2 can be considered coherent when a stable phase relationship between the partial reflections exists. Stable phase differences can be expected when the coherence length of the source is more than twice the length of the individual cavity. In this case, the individual reflections must be viewed as reflected electrical fields. The accumulated reflected field depends on the wavelength and the difference of polarization states between the partial reflections. The largest reflection occurs when all fields have the same polarization state and add in phase. In this case, the total power reflection is the square of all field reflections.
able to locate multiple reflections spatially resolved. It offers very high sensitivity but the measurement range is limited by the moving distance of the interferometer (usually around 10 cm).

- OTDR (optical time domain reflectometry): This method, based on the reflectance on optical pulses, is well known in the area of optical fiber test. With specialized versions of OTDRs (sometimes referred to as “Millimeter OTDR”) also components can be tested for backreflection.

In the following we will concentrate on OCWR solutions.

**Return loss measurements using OCWR technique**

The basic measurement setup for return loss measurements is shown in figure 6. Light is launched through an optical coupler to the connected device under test (DUT). The part of optical power that is reflected by the device travels back and is detected by the receiver in the second arm of the coupler. The return loss measurement value is simply given by the ratio between the incident power at the DUT and the reflected power (usually expressed in dB).

**Principles of Return Loss Measurements**

**Overview**

There are three different methods that are generally used to measure Return Loss in optical components. Each of it has its typical advantages and drawbacks:

- OCWR (optical continuous-wave reflectometry): This is an integral (i.e. only the sum of all occurring reflections can be measured) test method best suited to test single reflections. One main advantage is the high sensitivity and straightforward implementation
- OCDR (optical coherence domain reflectometry): This method, based on white light interferometry, is
The measurement challenge is twofold:

1. One has to determine the fraction of POUT that is emitted into the DUT (PIN). The reflected Power PRFL passing the coupler (PDDET) is unknown.
2. Another unknown parameter are the reflections caused by the setup itself. The magnitude of these so-called “parasitics” must also be determined.

These two values usually have to be determined by a user calibration. Because these quantities are influenced by a variety of different parameters that are not stable over time. A factory calibration is insufficient.

Calibration

Prior to measuring the DUT the Return-Loss module has to be calibrated.

The calibration eliminates wavelength dependencies, coupler directivity, insertion losses, backscattering and other non-ideal characteristics of the measurement setup.

Assuming that there are no power dependent losses within the setup, all dependencies are linear.

\[
P_{\text{IN}} = P_S \cdot k_1, \quad (1)
\]

\[
P_{\text{REF}} = P_{\text{IN}} \cdot R = P_S \cdot k_1 \cdot R, \quad (2)
\]

\[
P = P_{\text{REF}} \cdot k_2 + P_S \cdot s. \quad (3)
\]

The power at the detector during the reference measurement is then given by:

\[
P = P_S \cdot k_1 \cdot k_2 \cdot R + P_S \cdot s \quad (4)
\]

The constants 1 2 k , k are multipliers representing the coupler ratio, while the constant s stands for the scattering factor. The scattering factor accounts for any directivity of the coupler, backscatter in the fiber and reflections of the connectors. R is the reflectivity of the DUT.

This yields the following equation:

\[
P = P_S \cdot c \cdot R + P_S \cdot s \quad (5)
\]

with: \( c = k_1 \cdot k_2 \).

If we specify the parameters for the reference calibration we get:

\[
P_{\text{REF}} = P_S \cdot c \cdot R_{\text{REF}} + P_S \cdot s \quad (6)
\]

To determine the system’s parasitics the optical line must be terminated, so that its reflectivity R is zero:

\[
P_{\text{PARA}} = P_S \cdot c \cdot R_{\text{PARA}} + P_S \cdot s \quad ; \quad R_{\text{PARA}} = 0
\]

\[
P_{\text{PARA}} = P_S \cdot s \quad (7)
\]

Measuring the DUT it gives a third equation:

\[
P_{\text{DUT}} = P_S \cdot c \cdot R_{\text{DUT}} + P_S \cdot s \quad (8)
\]

Substituting equation 7 into equations 6 and 8, one obtains two equations:

\[
P_{\text{REF}} - P_{\text{PARA}} = P_S \cdot c \cdot R_{\text{REF}} \quad (9)
\]

\[
P_{\text{DUT}} - P_{\text{PARA}} = P_S \cdot c \cdot R_{\text{DUT}} \quad (10)
\]
Dividing equation 10 by 9 yields:

\[ R_{DUT} = \frac{P_{DUT} - P_{PARA}}{P_{REF} - P_{PARA}} \cdot R_{REF} \]  \hspace{1cm} (11)

The return loss of the DUT is given by:

\[ RL_{DUT} = -10 \log_{10} R_{DUT} \]  \hspace{1cm} (12)

while the return loss of the reference reflection is given by:

\[ RL_{REF} = -10 \log_{10} R_{REF} \]  \hspace{1cm} (13)

while the return loss of the reference reflection is given by:

\[ RL_{DUT} = -10 \log_{10} \left( \frac{P_{DUT} - P_{PARA}}{P_{REF} - P_{PARA}} \right) + RL_{REF} \]  \hspace{1cm} (14)

Hands on:

To perform the reference calibration the reference cable must be connected to the RL module output. Enter this reference value by pressing ref-cal on the mainframe or by a remote command, e.g. via GPIB.

A manual termination – usually by twisting the fiber into loops around a pen or mandrel with a diameter of five to seven millimeters – is easy to apply. Often literature recommends a total of five fiber loops. Since the termination calibration value (Ppara) represents the parasitics, it is important to keep this value as low as possible to obtain the maximum measurement range. In practical measurements the use of ten loops has proven to be on the safe side.

If this procedure appears to be harmful to the fiber or if an automated termination calibration is required, it is possible to use an attenuating device for termination, such as the 8156A Optical Attenuator.

Make sure to set the attenuator to maximum and enable the output to avoid any influence of the shutter system. Please note that the optical system of the inserted device will have an influence on the overall parasitics, so measurement results may vary compared to the manual termination. However the influence of the 8156A on the termination calibration is very small because of the high return loss of the attenuator itself.

Usually, the termination value is stored in the instrument (for the Keysight 8161X return loss module press term-cal on the mainframe or send a remote command).

It is important to protect the reference cable from damage. Any physical contact can alter the surface and its RL value. It is safe to make a non-contact connection to a power meter, for example to measure the reference cable’s Insertion Loss. Therefore the measurement should use a patchcord other than the reference cable.

To make up for the difference between the patchcords’ Insertion Loss an additional factor called Front Panel Delta (FP Delta) was introduced as additional parameter in the Keysight family of Return Loss meters.

For a more detailed description of the calibration procedure – including the Front Panel Delta calibration – please refer to the return-loss meter (RLM) manual.

The calibration procedure is usually performed once at the beginning of a set of measurements. However it must be repeated if one of the main components (such as source, RLM) is exchanged!

Measuring the DUT

After the calibration is complete, the system is ready to measure. The DUT is connected to the RLM output and the RL value is displayed in the result field for the RL channel or by the remote software.

To ensure only reflections from the DUT are measured, it is important to terminate the system close to the DUT’s end.

It is strongly recommended that angled connectors (so called High Return Loss connectors) are used whenever possible. Straight connections have higher intrinsic return loss compared to angled connectors. This increases the risk of building up cavities that can cause unwanted interference effects.

If there are difficulties to get a stable RL reading try the following:

– Check all connecting pairs for defective surfaces and clean them thoroughly.
– Exchange patchcords, varying their length.
– Switch on Coherence Control (if applicable).
– Increase the averaging time. A typical measurement time is one second.

Example measurements are described in the following sections.
New Keysight Return Loss Modules

The Keysight 8161xA series Return Loss modules are intended for the use in Keysight 8163A or 8163B Lightwave Multimeter, the Keysight 8164B Lightwave Measurement System and the Keysight 8166B Lightwave Multichannel System.

- 81610A Return Loss Module
- 81611A, internal source, 1310 nm
- 81612A, internal source, 1550 nm
- 81613A, two internal sources, 1310/1550 nm
- 81614A, two internal sources, 1550/1625 nm

All modules allow the use of an external light source in the wavelength range of 1250 to 1640 nm. If connected to a tunable laser source (TLS) the modules are capable of performing a return loss measurement during a wavelength sweep.

The key feature of the 8161xA module series is an additional power sensor which serves as a monitoring diode for the source input.

The monitor diode records the input power and the return power simultaneously. Both readings are used for the calculation of the return loss value. Benefits:

- Any power fluctuations of internal or external power sources have no influence on the return loss measurement.
- Changes in the source power range or the attenuation do not affect the accuracy of the return loss measurement.
- These features mean, re-calibration is needed less often.

In addition the Keysight 8163 Mainframe with firmware version 3.0 or greater offers a GUI guided calibration procedure.

Other advantages of the Keysight 8161xA are an extended dynamic range and the larger wavelength range (see specifications for details).

![Figure 8: Principle of RL measurement of the new Keysight Return Loss modules.](image)

If we take the Monitoring diode into consideration, the equations become a little more complex. The power at the detector during the reference measurement is given by:

\[ P = P_s \cdot t_2 \cdot k_1 \cdot k_2 \cdot R + P_s \cdot t_2 \cdot s \]  \hspace{1cm} (15)

with: \[ M = t_1 \cdot P_s, \quad c_1 = t_2 \cdot k_1 \cdot k_2, \quad c_2 = t_2 \cdot s \]

The constants \(1, 2, 1, 2, k, t, t\) are multipliers representing the coupler ratios, while the constant \(s\) stands for the scattering factor. The scattering factor accounts for any directivity of the coupler, backscatter in the fiber and reflections of the connectors. \(R\) is the reflectivity.

This gives us the following equation:

\[ P = c_1 \cdot M \cdot R + c_2 \cdot M \]  \hspace{1cm} (16)

If we specify the parameters for the reference calibration we get:

\[ P_{REF} = c_1 \cdot M_{REF} \cdot R_{REF} + c_2 \cdot M_{REF} \]  \hspace{1cm} (17)

To determine the system’s parasitics the optical line must be terminated, so that its reflectivity is zero:

\[ P_{PARA} = c_1 \cdot M_{PARA} \cdot R_{PARA} + c_2 \cdot M_{PARA}; \quad R_{PARA} = 0 \]

\[ P_{PARA} = c_2 \cdot M_{PARA} \Leftrightarrow c_2 = \frac{P_{PARA}}{M_{PARA}} \]  \hspace{1cm} (18)
When measuring the DUT it gives us a third equation:

$$P_{DUT} = c_1 \cdot M_{DUT} \cdot R_{DUT} + c_2 \cdot M_{DUT}$$  \hspace{1cm} (19)

Substituting equation 18 into equations 17 and 19 yields:

$$P_{REF} - \frac{M_{REF}}{M_{PARA}} \cdot P_{PARA} = c_1 \cdot M_{REF} \cdot R_{REF}$$  \hspace{1cm} (20)

$$P_{DUT} - \frac{M_{DUT}}{M_{PARA}} \cdot P_{PARA} = c_1 \cdot M_{DUT} \cdot R_{DUT}$$  \hspace{1cm} (21)

If we divide equation 21 by 20, we get:

$$R_{DUT} = \frac{M_{REF}}{M_{DUT}} \cdot \frac{P_{DUT}}{P_{REF}} - \frac{M_{REF}}{M_{PARA}} \cdot \frac{P_{PARA}}{P_{REF}} \cdot R_{REF}$$  \hspace{1cm} (22)

The return loss of the DUT is given by:

$$RL_{DUT} = -10 \log_{10} R_{DUT}$$  \hspace{1cm} (23)

while the return loss of the reference reflection is given by:

$$RL_{REF} = -10 \log_{10} R_{REF}$$  \hspace{1cm} (24)

Thus we get the following formula to calculate the return loss:

$$RL_{DUT} = -10 \log_{10} \left( \frac{M_{REF}}{M_{DUT}} \cdot \frac{P_{DUT}}{P_{REF}} - \frac{M_{REF}}{M_{PARA}} \cdot \frac{P_{PARA}}{P_{REF}} \right) + RL_{REF}$$  \hspace{1cm} (25)

Usually the RL is measured using another patchcord as the reference cable. To make up for the difference between the patchcords’ properties an additional factor called Front Panel Delta (FPDelta) was introduced.

The RL measured with respect to the FPDelta is:

$$RL_{DUT,FP} = RL_{DUT} + 2 \cdot FPDelta$$  \hspace{1cm} (26)

**Single wavelength measurements**

Single or static wavelength measurements can be performed using a variety of light sources.

Due to their different physical properties, each source will deliver RL readings of varying accuracy. The ideal source for return loss measurements would have an infinitely broad spectrum. Because this would eliminate all power fluctuations due to self interference. On the other hand with such a source a wavelength dependent measurement would not be possible at all.

Figures 9 and 10 show the RL and the standard deviation of a set of RL measurements using different laser sources. The setup utilized an 8156A optical attenuator that was spliced directly to the output of a 81610A RL meter in order to avoid any parasitic return loss from the connection. The DUT was just a cleaved fiber end. This setup allows for an adjustable return loss setting.

The sources tested are:

- Tunable Laser Source (TLS) based on a external cavity laser
- An ASE source (amplified spontaneous emission source)
- A Fabry-Perot based fixed Laser Source (FLS)
- FLS with active Coherence Control (FLS w. CC)
- Distributed Feedback Laser (DFB)
- DFB with active Coherence Control (DFB w. CC)

The RL was measured over increasing attenuation factors.

![Figure 9: Measured RL vs. nominal RL for different types of laser sources.](image)
Wavelength dependent measurements

The Keysight 8161xA series Return Loss Modules will support return loss measurement during a continuous wavelength sweep ("lambda scan") using a TLS. (Rev. 3.0 of the 816X VXI-PNP driver required).

The swept return loss procedure is as straightforward as the measuring at a fixed wavelength.

Figure 11: Calibration procedure for swept Return Loss.

The calibration procedure, shown in figure 6, is basically the same as in fixed wavelength setups. The wavelength dependency of the RL power meters can be neglected, but for the most accurate results it is suggested that the ref–cal and term–cal values are recorded over the desired wavelength range.

Measuring the calibration values over wavelength directly compensates for the spectral sensitivity of components, eliminating spectral ripple.

Figure 7 shows the measurement setup.

Figure 12: Swept Return Loss measurement setup.
From the calibration we gain the following values:

\[ P_{\text{REF}}(\lambda), M_{\text{REF}}(\lambda), P_{\text{PARA}}(\lambda), M_{\text{PARA}}(\lambda). \]

The measurement of the DUT yields to:

\[ P_{\text{DUT}}(\lambda) \text{ and } M_{\text{DUT}}(\lambda). \]

Sample measurements:

Open FCPC connector

The following figures show the swept Return Loss measurement of an open FC/PC connector at the output of an 8156A Optical Attenuator.

Though the figure for 34 dB attenuation shows serious noise, it is possible to determine a RL value.

The standard deviation from a linear trendline is less than 0.5 dB for 30 dB attenuation and less than 1.35 dB for 34 dB attenuation. After applying a low pass filter algorithm the data are definitely usable, see Figure 10. The analysis used was Discrete Fourier Transform to determine spectrum and power spectral density of data; lowpass filter of measurement data.)
The influence of the outputs’ state is clear.

The straight connector with its glass/air junction acts as a mirror yielding a low RL value. The combshaped row of peaks is an interference effect due to self-interference.

The measurement dynamic is reduced because this FBG has only straight connectors. Angled (high RL) connectors would probably provide a higher signal-to-noise ratio and therefore better RL values.

Figure 12 shows the influence of termination on the measured RL value.

The passband curve shows a similar interference effect as the RL measurement in figure 11, again a consequence of the use of straight connectors.

The good results of the TLS in the wavelength dependent measurements compared to the fixed wavelength measurements have to be explained: During the wavelength sweep the laser is continuously tuned through the desired wavelength range. The lambda scan is performed at a speed of 10 nm/s while the power measurement is triggered with each increment of the chosen step size. In between these steps the power measurement continues, therefore the RL module’s power meters virtually integrate the incident power over time and resulting wavelength increments.

For example the FBG measurement used a step size of 10 pm which is also the integrating wavelength range.

The swept RL measurement is less sensitive towards interference effects, making the tunable laser a good tool for wavelength dependent measurements.

Acknowledgement

The authors want to thank Dr. Oliver Rösch for providing some measurement data.

Related literature


8164A Lightwave Measurement System, Product Overview p/n 5968-3405E


Figure 16: Return Loss of FBG, comparing open and terminated outputs.

The straight connector with its glass/air junction acts as a mirror yielding a low RL value. The combshaped row of peaks is an interference effect due to self-interference.

Figure 17: Return Loss and Insertion Loss of a Fiber Bragg Grating over a wavelength range of 1535 to 1550 nm.
Evolving Since 1939

Our unique combination of hardware, software, services, and people can help you reach your next breakthrough. We are unlocking the future of technology. From Hewlett-Packard to Agilent to Keysight.

myKeysight
www.keysight.com/find/mykeysight
A personalized view into the information most relevant to you.

http://www.keysight.com/find/emt_product_registration
Register your products to get up-to-date product information and find warranty information.

Keysight Services
www.keysight.com/find/service
Keysight Services can help from acquisition to renewal across your instrument’s lifecycle. Our comprehensive service offerings—one-stop calibration, repair, asset management, technology refresh, consulting, training and more—helps you improve product quality and lower costs.

Keysight Assurance Plans
www.keysight.com/find/AccurancePlans
Up to ten years of protection and no budgetary surprises to ensure your instruments are operating to specification, so you can rely on accurate measurements.

Keysight Channel Partners
www.keysight.com/find/channelpartners
Get the best of both worlds: Keysight’s measurement expertise and product breadth, combined with channel partner convenience.

For more information on Keysight Technologies’ products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus

Americas
Canada (877) 894 4414
Brazil 55 11 3351 7010
Mexico 001 800 254 2440
United States (800) 829 4444

Asia Pacific
Australia 1 800 629 485
China 800 810 0189
Hong Kong 800 938 693
India 1 800 11 2626
Japan 0120 (421) 345
Korea 080 769 0800
Malaysia 1 800 888 848
Singapore 1 800 375 8100
Taiwan 0800 047 866
Other AP Countries (65) 6375 8100

Europe & Middle East
Austria 0800 001122
Belgium 0800 58580
Finland 0800 523252
France 0805 980333
Germany 0800 6270999
Ireland 1800 832700
Israel 1 809 343051
Italy 800 599100
Luxembourg +32 800 58580
Netherlands 0800 0233200
Russia 8800 5093286
Spain 800 000154
Sweden 0200 892255
Switzerland 0800 805353
Opt. 1 (DE)
Opt. 2 (FR)
Opt. 3 (IT)
United Kingdom 0800 0260637

For other unlisted countries:
www.keysight.com/find/contactus
(BP-9-7-17)

DEKRA Certified
ISO 9001:2015 Quality Management System

www.keysight.com/go/quality
Keysight Technologies, Inc.
DEKRA Certified ISO 9001:2015
Quality Management System

This information is subject to change without notice.
© Keysight Technologies, 2017
Published in USA, December 1, 2017
5988-3435EN
www.keysight.com