Return Loss Solutions with the Agilent 8161X Return Loss Modules

Application Note

Mathias Lischke, Andreas Gerster, Christian Hentschel,
Agilent Technologies, OCMD

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 Agilent 8161X Return Loss modules is explained for various use cases.

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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.

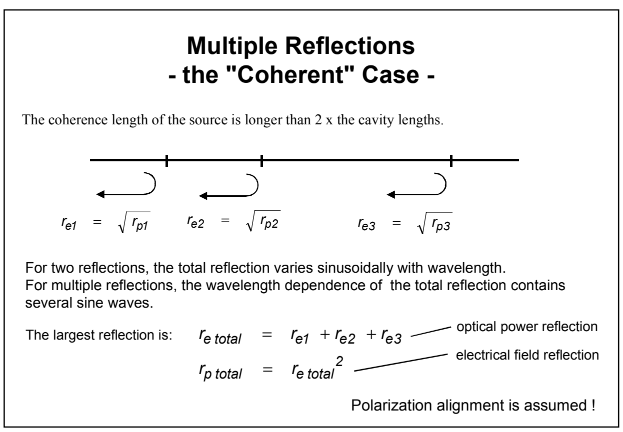

Figure 2: Coherent superposition of multiple reflections

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.

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.

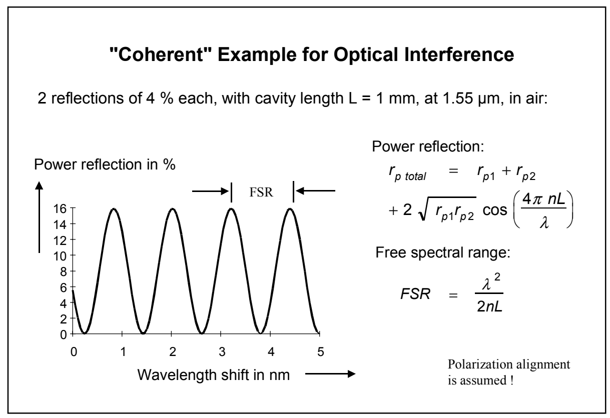

Figure 3: Calculated wavelength dependence of a cavity with an FSR of 1.2 nm.

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.

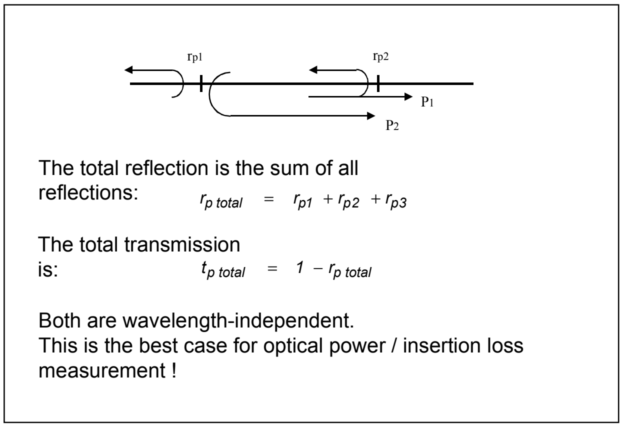

Figure 4: The incoherent case of multiple reflexions

In an optical communication system, incoherent reflections generate baseband noise by mixing in the photodetector; the two reflected fields have a random phase relationship. Mixing then creates an image of the optical spectrum at low frequencies as illustrated in figure 5.

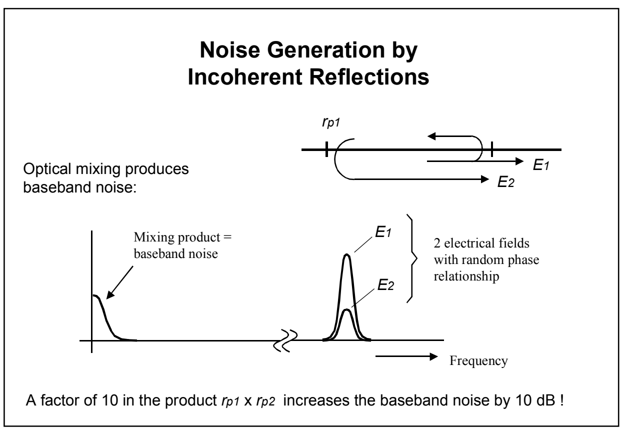

Figure 5: Baseband Noise Generation by incoherent reflections

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 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 reflectometery): 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).

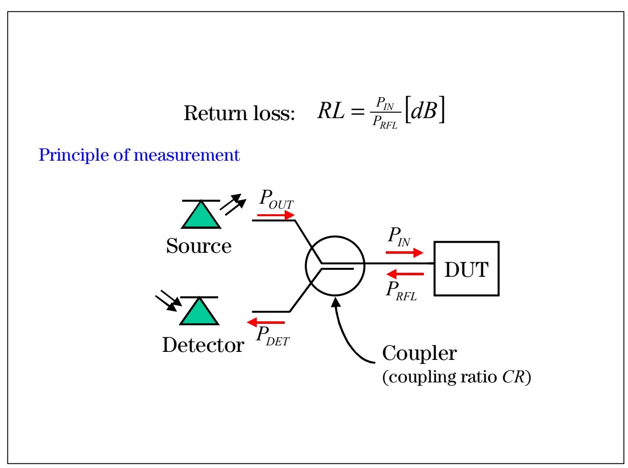

Figure 6: Principle of Return Loss measurement using OCWR method. The light emitted by the source is partly reflected by the Device under Test (DUT). A coupler leads part of the reflected light to a photodetector.

The measurement challenge is twofold:

1. One has to determine the fraction of P_{OUT} that is emitted into the DUT (P_{IN}). The reflected Power P_{RFL} passing the coupler (P_{DET}) 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.

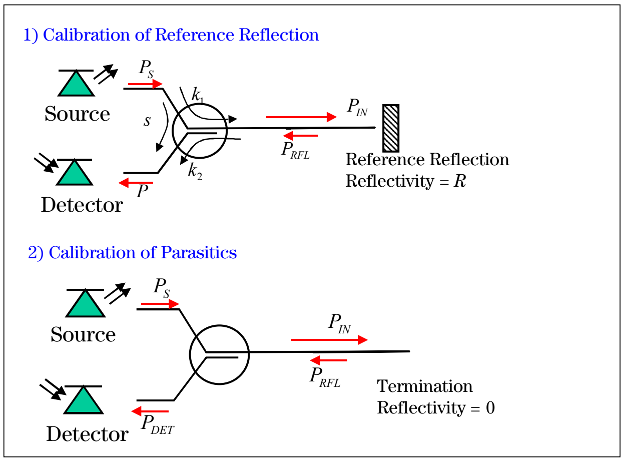

Figure 7: Necessary steps for the calibration of Reference Reflection and Parasitic Reflections.

The user calibration has two steps (Figure 7):

1. *Reference Calibration*. A device of known reflectivity *R* is brought into the system as a reference for the RL module (E.g.: Agilent 81000BR Reference Reflector or the Agilent 81610CC Reference Cable).

2. *Termination Calibration*. This step compensates for parasitic reflections in the system. Usually a patchcord terminated by winding it around a mandrel (approx. 5 to 10 turns) is used for this step.

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

$$P_{IN} = P_S \cdot k_1 , \quad (1)$$

$$P_{RFL} = P_{IN} \cdot R = P_S \cdot k_1 \cdot R , \quad (2)$$

$$P = P_{RFL} \cdot k_2 + P_S \cdot s . \quad (3)$$

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 k_1, k_2 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:

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

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

$$P_{PARA} = P_S \cdot c \cdot R_{PARA} + P_S \cdot s ; \quad R_{PARA} = 0$$

$$P_{PARA} = P_S \cdot s \quad (7)$$

Measuring the DUT it gives a third equation :

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

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

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

$$P_{DUT} - P_{PARA} = P_S \cdot c \cdot R_{DUT} \quad (10)$$

Dividing equation 10 by 9 yields:

$$R_{DUT} = \frac{P_{DUT} - P_{PARA}}{P_{REF} - P_{PARA}} \cdot R_{REF} \qquad (11)$$

The return loss of the DUT is given by:

$$RL_{DUT} = -10\log_{10} R_{DUT} \qquad (12)$$

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

$$RL_{REF} = -10\log_{10} R_{REF} \qquad (13)$$

Resulting in the following formula to calculate the return loss:

$$RL_{DUT} = -10\log_{10}\left(\frac{P_{DUT} - P_{PARA}}{P_{REF} - P_{PARA}}\right) + RL_{REF}. \qquad (14)$$

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 Agilent 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* (*FPDelta*) was introduced as additional parameter in the AGILENT 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 Agilent Return Loss Modules

The Agilent 8161xA series Return Loss modules are intended for the use in Agilent 8163A or 8163B Lightwave Multimeter, the Agilent 8164B Lightwave Measurement System and the Agilent 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 featured mean, re-calibration is needed less often.

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

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

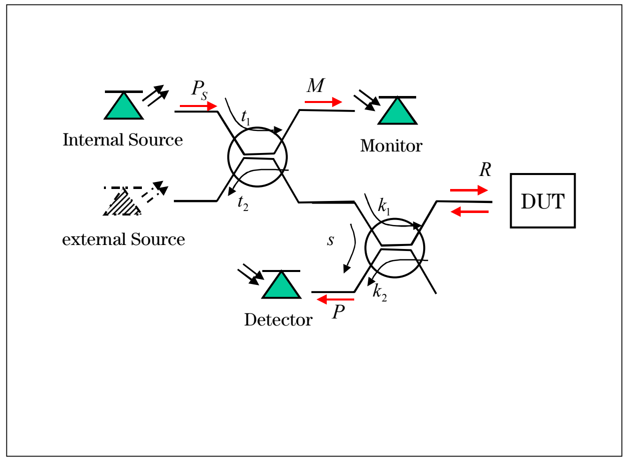

Figure 8: Principle of RL measurement of the new Agilent Return Loss modules.

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:

$$P = P_S \cdot t_2 \cdot k_1 \cdot k_2 \cdot R + P_S \cdot t_2 \cdot s \qquad (15)$$

with: $M = t_1 \cdot P_S, \quad c_1 = \frac{t_2}{t_1} \cdot k_1 \cdot k_2, \quad c_2 = \frac{t_2}{t_1} \cdot s$

The constants k_1, k_2, t_1, t_2 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:

$$P = c_1 \cdot M \cdot R + c_2 \cdot M \qquad (16)$$

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

$$P_{REF} = c_1 \cdot M_{REF} \cdot R_{REF} + c_2 \cdot M_{REF} \qquad (17)$$

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

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

$$P_{PARA} = c_2 \cdot M_{PARA} \Leftrightarrow c_2 = \frac{P_{PARA}}{M_{PARA}} \qquad (18)$$

When measuring the DUT it gives us a third equation :

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

Substituting equation 18 into equations 17 and 19 yields:

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

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

If we divide equation 21 by 20, we get:

$$R_{DUT} = \frac{M_{REF}}{M_{DUT}} \cdot \frac{P_{DUT} - \frac{M_{DUT}}{M_{Para}} \cdot P_{Para}}{P_{REF} - \frac{M_{REF}}{M_{Para}} \cdot P_{Para}} \cdot R_{REF} \qquad (22)$$

The return loss of the DUT is given by:

$$RL_{DUT} = -10 \log_{10} R_{DUT} \qquad (23)$$

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

$$RL_{REF} = -10 \log_{10} R_{REF} \qquad (24)$$

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

$$RL_{DUT} = -10 \log_{10} \left(\frac{M_{REF}}{M_{DUT}} \frac{P_{DUT} - \frac{M_{DUT}}{M_{Para}} \cdot P_{Para}}{P_{REF} - \frac{M_{REF}}{M_{Para}} \cdot P_{Para}} \right) + RL_{REF} \,. \qquad (25)$$

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:

$$RL_{DUTmeas} = RL_{DUT} + 2 \cdot FPDelta \qquad (26)$$

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.

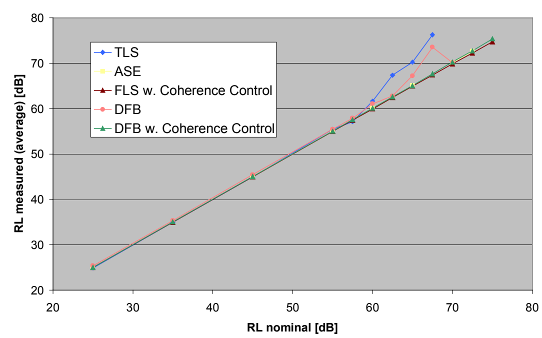

Figure 9: Measured RL vs. nominal RL for different types of laser sources .

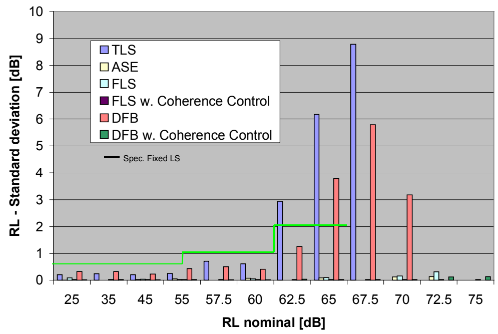

Figure 10: Standard deviation of RL measurements, comparing various sources.

The horizontal lines in figure 5 represent the specification for AGILENT's return loss meter used with external Fabry-Perot sources with active Coherence Control (Spec. FLS). The specification for broadband sources is 50 % below of the FLS spec. values.
At low attenuation levels (corresponding to low return loss values) all sources provide accurate RL values. As expected, the broadband sources, especially the ASE, perform best, providing the most stable readings.
However, at a nominal RL of more than 60 dB the narrow-band sources produce a higher uncertainty and unreliable data. Due to their relatively long coherence length, interference occurs which disturbs the power measurement.
Using the built in Coherence Control, which broadens the source’s linewidth by modulating the laser diode, works fine with the Fabry-Perot and the DFB sources but has almost no effect with the TLS.
Therefore the TLS is not the first choice for fixed wavelength RL measurement applications where the highest accuracy is needed.
A TLS is advantageous in turn to perform wavelength dependent measurements, as described in the following paragraph.

With the knowledge of the lasers’ properties one can easily decide which source will provide the best results in the required application.

Wavelength dependent measurements

The Agilent 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.

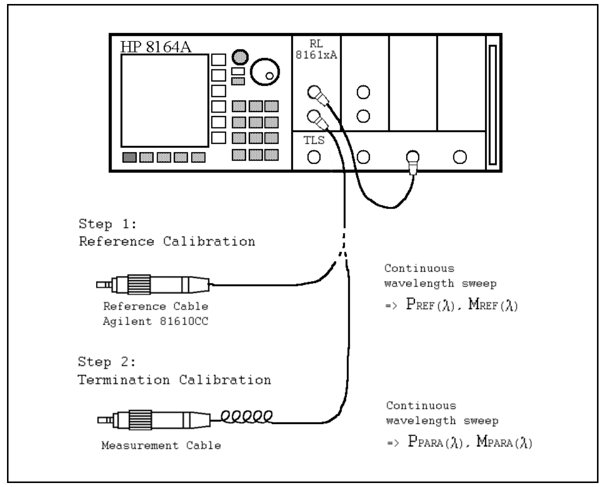

Figure 11: Calibration procedure for swept Return Loss.

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.

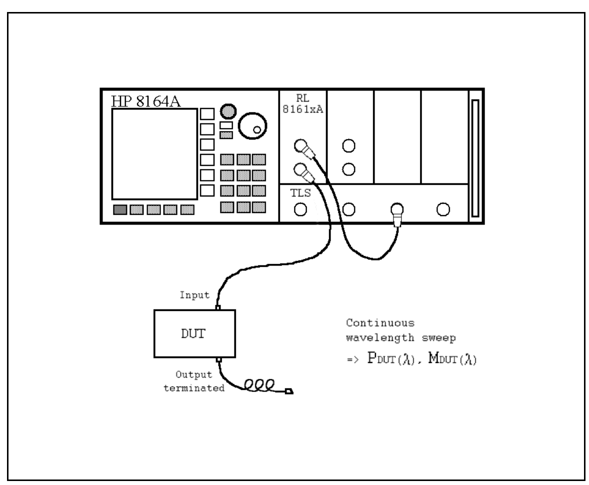

Figure 12: Swept Return Loss measurement setup.

From the calibration we gain the following values:
$P_{REF}(\lambda)$, $M_{REF}(\lambda)$, $P_{PARA}(\lambda)$, $M_{PARA}(\lambda)$.

The measurement of the DUT yields to:
$P_{DUT}(\lambda)$ and $M_{DUT}(\lambda)$.

These values are used to calculate the return loss using formula (25) with respect to wavelength.

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.

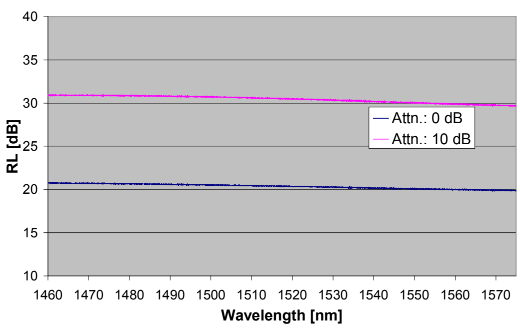

Figure 13: Return Loss of an open FC/PC connector with optical attenuator set to 0 and 10 dB total attenuation.

The nominal RL at an attenuation of 0 dB consists of the RL of the connector, which is approximately 15 dB, plus two times the insertion loss of the optical attenuator (3 dB). This equals a nominal return loss of approximately 21 dB, which can be found in the 0 dB attenuation curve of figure 8.

Setting the attenuator to 5 dB affects the signal on it's way back and forth through the setup and results in a total attenuation of 10 dB. The nominal RL is 31 dB.

The standard deviation from a linear trendline (least square fit) is less than 0.04 dB without attenuation and less than 0.08 dB at 10 dB total attenuation. This figure gives a good impression of the quality of the measurement. The slight change in return loss over wavelength is caused by the wavelength depended insertion loss of the attenuator. Therefore only the deviation from a linear behavior is considered.
Measuring at high attenuation settings (and therefore lower signal levels) increases noise, which results in a higher measurement uncertainty.

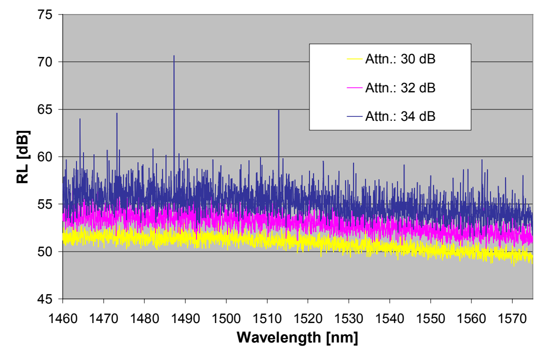

Figure 14: Return Loss of an open FCPC connector with optical attenuator set to 30, 32 and 34 dB total attenuation.

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 Tansform to determine spectrum and power spectral density of data; low-pass filter of measurement data).

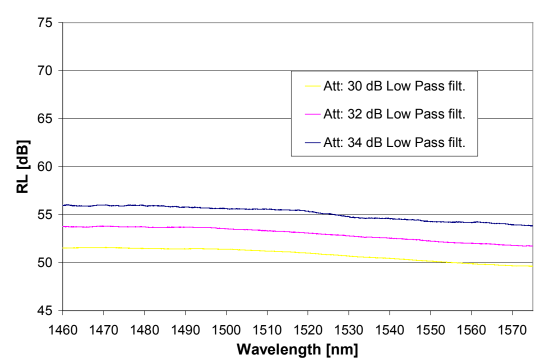

Figure 15: Low Pass filtered data of figure 14.

Fiber Bragg Grating

The following figures show the wavelength dependent RL of a typical Fiber Bragg Grating (FBG).

The setup used the low SSE output of a 81680A TLS in a 8164A Lightwave Measurement System as an external source for the 81610A RLM.
The DUT was a Fiber Bragg Grating. The Grating has straight FC/PC connector input and outputs.

Figure 11 shows the influence of termination on the measured RL value.

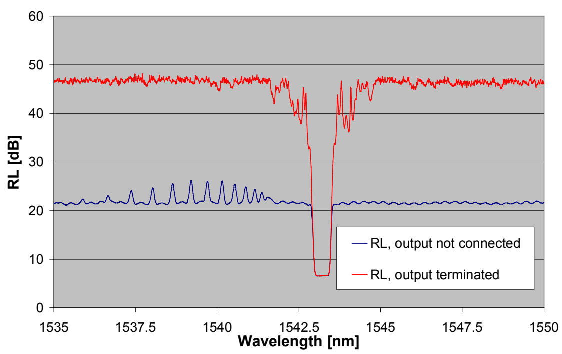

Figure 16: Return Loss of FBG, comparing open and terminated outputs.

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 comb-shaped 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 to corresponding insertion loss measurements for the same FBG device. The insertion loss values correspond quite well with the return loss data.

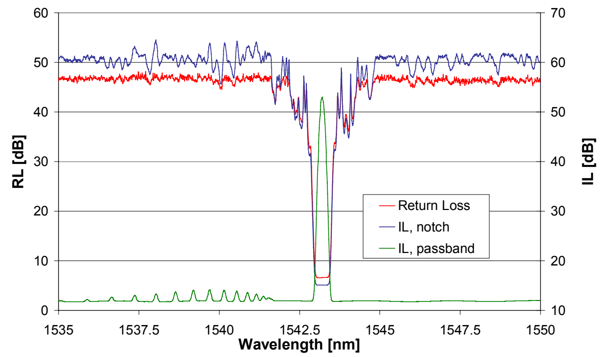

Figure 17: Return Loss and Insertion Loss of a Fiber Bragg Grating over a wavelength range of 1535 to 1550 nm.

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.

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(tel) 1 800 629 485
(fax) (61 3) 9210 5947

New Zealand:
(tel) 0 800 738 378
(fax) 64 4 495 8950

Asia Pacific:
(tel) (852) 3197 7777
(fax) (852) 2506 9284

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Related Agilent literature:

8164A Lightwave Measurement System, configuration guide, **p/n 5968-0062E**

8164A Lightwave Measurement System, product overview **p/n 5968-3405E**

Müller, E., Rück, C., Born, T., Wagemann, E.U., Leckel, E.: "Fast and accurate determination of a tunable laser wavelength and its application to DWDM components", paper WB 2, Optical Fiber Conference, Baltimore, March 2000

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