VIAVI Solutions

White Paper

Measure OTDR, return, and insertion loss on a single port to characterize optical links

A combined OTDR and loss test set for fast measurements of optical links enables sequential bidirectional measurement of insertion and optical return loss through a single optical connection using continuous wave method.

Introduction to the measurement method

The ever increasing number of subscribers together with increasing demand for more and more bandwidth means providers must install fiber optic cables more quickly. Verifying compliance with system manufacturer specifications is required during the installation and acceptance testing phase[1]. These tests should be easy to perform so that the field operators can run them in less time. The VIAVI tool set offers an integrated test function that reduces testing time and deployment costs. To the best of our knowledge, no other commercially available product combines an OTDR and a loss test set that automatically performs these tests through a single optical connection. In this paper, we present a tool set enabling fast insertion loss (IL) and optical return loss (ORL) measurements using optical continuous wave techniques and characterizing its performance using theoretical analysis and experimental validation. Currently, users can choose among these tested wavelengths 1310, 1550, and 1625 nm.

The tool set comprises a set of two measurement units referred to as Units A and B, each plugged into a base platform. Each unit includes multiple lasers and an optical power meter combined in a single fiber output using a 3-dB coupler as in any OTDR. These devices may operate with continuous wave (CW) light in addition to pulsed light used for OTDR operation. Each base platform may also integrate an additional optical power meter that is required for ORL measurements. For correct operation, users should perform a reference procedure before the link measurement, as Figure 1 shows, which may be completed using either the side-by-side (SbyS) or loopback (LB) method. Additionally, a zero-offset ORL reference is needed for ORL measurements.

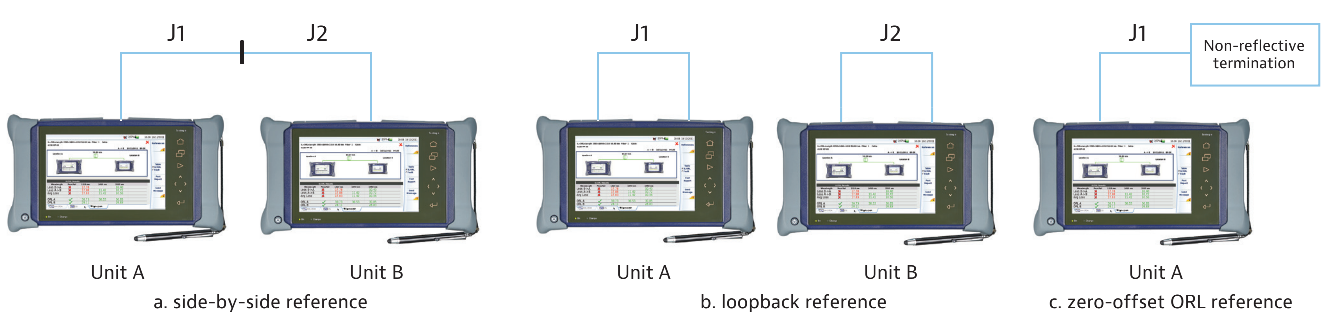

Figure 1. Reference procedures for side-by-side (a), loopback (b), and zero-offset ORL reference (c)

The SbyS reference mode can be used to perform IL measurements. The two units are connected to each other, as shown in Figure 1a, using two patch cords, J1 and J2. The reference step enables the power meters for both units to measure the optical power P_{Tx} emitted by the laser of the other unit minored by the IL of the two patch cords.

However, it may not always be possible to perform this procedure because of the distance between each end of the link being tested; therefore, technicians can use the LB reference mode, as described in Figure 1b, where each of the units is connected to the power meter of its base platform. During the LB reference, the insertion loss of the patch cord, $IL_{patch\ cord}$, is first estimated as the difference between the measured power and the factory-calibrated power.

In a second step, the laser optical power is adjusted so that the measured power is $P_{TX} = -6.5$ dBm at the end of the patchcord. After performing any of these references, the patch cords must remain connected to the measurement units or an IL variation will occur upon reconnection. In addition to the LB reference procedure, ORL link measurements require knowledge of the zero-offset ORL power, or the measured power P_0, due to the return loss of the unit. Figure 1c shows how to perform the zero-offset ORL reference. Connecting the patch cord J1 between the unit and a non-reflective termination ensures a very low return loss. During the zero-offset ORL reference, the laser emits as the power meter on the same port measures the reflected optical power, P_0, which is linked to the directivity of the 3-dB coupler inside the measurement unit and to the return loss of the mated connectors at the unit output.

After completing the reference procedures, perform the link measurement step shown in Figure 2. Connect each of the units and their associated patch cord to either side of the link under test. IL and/or ORL measurements can then be performed on one or both units during the same test. The measured data is then displayed on both units. IL should be 40 dB or less, so that the two measurement units can communicate correctly with each other.

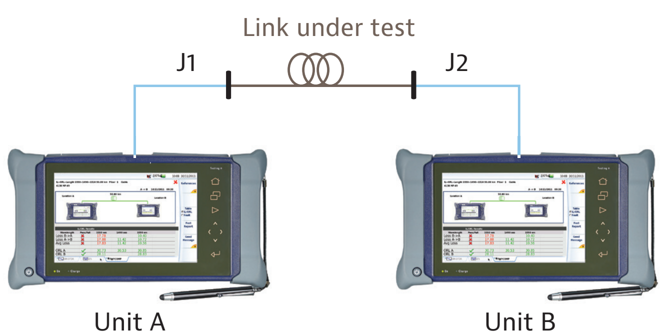

Figure 2. Experimental procedure for IL and ORL measurement of the link under test using the tool set

During the measurement, Unit A emits the optical power, P_{Tx}. Simultaneously, for an ORL measurement, Unit A also measures the reflected power P_{ORL} while Unit B's high reflectance (due to the photodiode) is hidden so that it does not affect the measured ORL value. For an IL measurement, Unit B measures the received optical power P_{Rx}. The IL value of the link is then calculated as the difference between the launched and received power using Formula 1 in SbyS mode and Formula 2 in LB mode. The ORL value is calculated using Formula 3. Each measurement lasts approximately 10 seconds for a given wavelength.

$$IL = P_{Tx} - P_{Rx} \qquad (1)$$

$$IL = -6.5 - (P_{Rx} + IL_{patch\ cord}) \qquad (2)$$

$$ORL = \frac{P_{Tx}}{P_{ORL} - P_0} \qquad (3)$$

Theoretical analysis and experimental validation of measurement uncertainties

Measurement uncertainty is linked to the various uncertainties of the devices we have used and the measurement methods. From previous uncertainty analyses, we have experimentally evaluated the standard uncertainties of the various components within the tool set that can be combined to calculate the standard uncertainties of the IL and ORL measurements.

For instance, using a SbyS reference, we must first consider the linearity of the power meter σ_{PM_lin} = 3.5 percent and the laser stability σ_{laser_stab} = 0.23 percent. We must also consider the fact that between reference and measurement stages, a back-to-back connector is added inducing an $\sigma_{connector}$ uncertainty of 1.16 percent regarding insertion loss. The polarization dependant loss (PDL) of the various components inside the unit must also be included, resulting in an σ_{PDL} uncertainty of 2.21 percent.

Finally, during the reference, the laser source emits a high power that saturates the power meter, even though it is mostly compensated for, it still results in an σ_{PM_sat} uncertainty of 2.35 percent, or about the amount of measured power, P_{Tx}. All of these uncertainties are independent and have a Gaussian distribution, except for the one linked to the PDL. The standard uncertainty of the IL measurement using the SbyS reference may be approximated using Formula 4.

$$\sigma_{IL\_side\text{-}by\text{-}side}^{2} \approx \sigma_{PM\_lin}^{2} + \sigma_{connector}^{2} + \sigma_{PM\_sat}^{2} + \sigma_{PDL}^{2} \qquad (4)$$

We obtained a standard uncertainty of 4.95 percent, or 0.21 dB, for the IL measurement using the SbyS reference. Similarly, we obtained standard uncertainties of 9.8 percent, or 0.4 dB, for the IL measurement and 8.3 percent, or 0.34 dB, for the ORL measurement using LB references.

In order to confirm the performance of this tool set, we built a calibrated link using a 2.5 km length of standard SMF-28 fiber, a 3-dB coupler, and two variable optical attenuators (VA), as shown in Figure 3. All the optical connectors were angle polished to reduce the return loss, except for those on each side of the 2.5 km fiber. Insertion loss between the coupler input and the fiber output can be varied up to 55 dB when adjusting VA-1.

For each setting of VA-1, we precisely measured the IL value using stable CW sources, a precision optical power meter (OLP-150), and the three jumper cable measurement methods[2]. During this measurement, VA-2 was set in Beam-Block mode, so that the reflected light would not interfere with the precise IL measurement. Likewise, when adjusting VA-2, the return loss measured from the coupler input may be varied between 10 and 55 dB. For each setting of VA-2, the ORL value was measured precisely using stable CW sources and a precision optical power meter as well as a calibrated 3-dB coupler with high directivity following the optical CW reflectometry technique[3]. For this measurement, VA-1 was set in Beam-Blocked mode to avoid impacting the measured ORL with the 2.5 km fiber Rayleigh backscattered light.

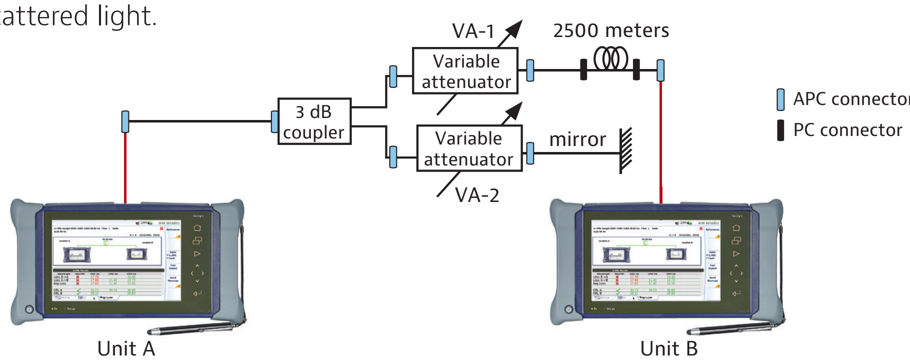

Figure 3. Calibrated link for experimental validation

Combining the different standard uncertainties of the devices used for the calibration of this link, or the laser stability, the linearity of the precision power meter, the PDL of the different components and the uncertainties due to the other components, provides the standard uncertainties of 0.1 and 0.2 dB, respectively, for calibrated values of IL and ORL. Additionally, the repeatability of the variable attenuators is less than 0.01 dB, ensuring a stable and precisely calibrated link.

We used this link to assess the performance of the IL and ORL measurements of our tool set with 14 different units, 8 of which operated at 1310 and 1550 nm while the other 6 also performed at 1625 nm. For each unit, we performed two series of measurements using either SbyS or LB reference modes and randomly picked the unit operating on the other side of the link. Because of the asymmetry of the calibrated link, only Unit A measured the link characteristics. We performed several tests to determine the accuracy of IL ranging from 6 to 40 dB in 1 dB steps, the accuracy of ORL ranging from 10 to 45 dB in 2 dB steps, as well as the repeatability, or the standard deviation, estimated for 30 measurements. From these results, we estimated the typical error compared with the measurements obtained during the calibration of the link. Note that we neglect the uncertainties of the measurements for the calibrated link because of their low impact. Table 1 details the statistics obtained with these 14 units.

	IL Measurement (SbyS mode)		**IL = 35 dB**	**ORL Measurement**		**ORL = 40 dB**
Wavelength	**Typical Error (dB)**	**Maximal Error (dB)**	**Repeatability (dB)**	**Typical Error (dB)**	**Maximal Error (dB)**	**Repeatability (dB)**
1310 nm	0.25	0.61	0.02	0.40	1.16	0.06
1550 nm	0.17	0.51	0.02	0.40	1.26	0.06
1625 nm	0.12	0.26	0.02	0.32	1.03	0.09

Table 1. Performance of the measurement with the tool set obtained with the 14 units

We first note the excellent repeatability of the tool set for both measurements as we obtain repeatabilities around 0.02 dB for IL and below 0.1 dB for ORL. An IL measurement using SbyS reference obtains a typical error below 0.25 dB and a maximum error of 0.61 dB. Similarly, an ORL measurement obtains a typical error below 0.4 dB and a maximum error of 1.26 dB. The IL measurement was also tested in LB mode and obtained a typical error around 0.4 dB and a maximum error of 1.09 dB. These values are consistent with the ones obtained using the analytical approach. The slightly degraded performance for the IL measurement in LB mode is due to the fact that, for this particular measurement mode, we combine several sources of uncertainty, in particular, the accuracies of the two power meters and the absolute power of the source during factory calibration.

Conclusion

We investigated a unique all-in-one OTDR, insertion and return loss measurement tool that enables fast and effective deployment of any fiber optic cable. We reported on the accuracy and repeatability of these measurements as well as the dynamic range of the measurement tool set confirming its importance for link characterization and acceptance testing.

References

[1] Fibre to the home Council Europe, FTTH test guidelines:
http://wiki.ftthcouncil.eu/index.php/FTTH_Handbook/FTTH_Test_Guidelines

[2] IEC standard 61280-4-2, "Fibre optic cable plant—Single-mode fibre optic cable plant attenuation," Chapter 5.1.3.

[3] IEC standard IEC-61300-3-6, "Fibre optic interconnecting devices and passive components—Basic test and measurement procedures—Examinations and measurements—Return loss," Chapter 4.2.

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