

Link loss measurement uncertainties: OTDR vs. light source power meter

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INTRODUCTION

The OTDR is a very efficient tool for characterizing the elements on a fiber link, such as connectors and splices, because it can measure loss, reflectance and location for each link element. The OTDR also measures the link loss. There are often questions about the degree of uncertainty of the link loss measurement obtained using an OTDR compared to that of the traditional light source power meter (LSPM). This application note compares both approaches to measuring link loss and provides step-by-step best practices to understand and minimize the degree of measurement uncertainty for each device.

Terminology note: Publications related to test equipment typically use *loss* while most standards use the term *attenuation*. Both words mean the same thing. This application note uses the term *loss*.

LSPM THEORETICAL UNCERTAINTIES

LSPM loss measurement uncertainty has been studied by the International Electrotechnical Commission (IEC) subcommittee 86C and a technical report, IEC TR 61282- 14 (2015). They provide an extensive review of all contributors to measurement uncertainty and a calculation spreadsheet. We will review here the main contributors to link loss measurement uncertainty. For further reading about uncertainty analysis, please refer to the IEC technical report.

Light source instability

LSPM measurement always implies that a reference measurement has been performed to determine the light source power level. This reference measurement is normally performed after a specified warm-up period, which is typically 15 minutes. Source instability—both short-term instabilities and long-term drift—will contribute to the uncertainty of the link loss measurement. Source instability is specified after a warm-up period, typically 15 minutes, for a stable environment in terms of temperature and humidity.

Light source wavelength

Light source wavelength is usually specified with a given tolerance, for example 850 nm \pm 30 nm. Since fiber attenuation exhibits some wavelength dependence, the link loss measurement varies as a function of the specific wavelength of a given light source. The link loss uncertainty associated to wavelength uncertainty depends on the nominal wavelength, the wavelength uncertainty range of the source and the loss value of the fiber under test. Only the loss associated to the fiber itself is considered in the uncertainty calculation since loss due to connectors (or splices) exhibit much less dependence on wavelength.

Multimode launch condition

For multimode fiber, loss depends on the power modal distribution of light within the fiber. A specific launch target has been specified by IEC (IEC 62614 and IEC 61280-4-1). At 850 nm, the loss uncertainty is 10% of the nominal loss (in dB), while it is 20% of the nominal loss at 1300 nm. Only the loss associated to connectors is considered in the uncertainty calculation since loss due to fiber itself exhibits much less dependence on launch condition.

Mating reproducibility

Loss measurement is performed while connecting reference test jumpers at the input and output of the link under test. Slight variations will occur when measurements are taken with different sets of launch and receive test cords.

Reference connector repeatability

The loss value will also vary slightly when the measurement is repeated using the same set of test jumpers following the disconnections and reconnections.

Typical uncertainty values

The table below shows typical uncertainty values for a multimode loss measurement using a one-cord reference, at 850 nm for a link of 300 m with a total loss of 1.6 dB.

Uncertainty contributor	Value	Comment
Light source instability	± 0.05 dB	Typical instability of a light source as per IEC 61282-14
Light source wavelength	Spectral loss dependence for 300 m at (850 ± 30) nm	Light source wavelength tolerance specified as per ISO/IEC-14763-3 (2014)
MM launch condition	$\pm 10\% \times 1.6$ dB (850 nm)	For encircled flux-compliant source
Mating reproducibility	± 0.1 dB	As per IEC 61282-14
Reference connector repeatability	± 0.05 dB	As per IEC 61282-14

Table 1. Typical uncertainty values.

All contributors are added in a statistical way, with a weight that is dependent on the type of uncertainties, to calculate the total uncertainty. In the example above, the total uncertainty is:

$$\text{Uncertainty} = \pm 0.27 \text{ dB (850 nm)}$$

The calculated uncertainty is higher than most people would have guessed. This is because the uncertainty is originating from the test instruments and also from the mating to and from the device under test (DUT) due to its spectral dependency.

“REAL LIFE” LSPM UNCERTAINTIES

To achieve the uncertainty calculated above, the measurement must be performed by a skilled operator following best practices. The following section details the main factors that need to be controlled.

Source drift after referencing

Source instability is specified after a warm-up period, typically 15 minutes, for a stable environment in terms of temperature and humidity. It is critical to allow sufficient warm-up time before performing the light source (LS) reference. Moreover, when the measurement is performed in an environment where the ambient temperature varies, the reference measurement must be repeated more frequently.

Reference test jumper

Uncertainty is calculated for measurements performed using reference-grade test jumpers. These test jumpers have lower maximum insertion loss (IL) and lower variability between samples than regular-grade test jumpers. The reference test jumper needs to be clean and without scratches; it should also be regularly inspected.

LSPM vs. optical loss test set

Uncertainties calculated in IEC TR 61282-14 (2015) apply to the measurements taken with a light source power meter based on a large area detector. The more advanced, automated, bidirectional optical loss test set (OLTS) is preferred for its convenience. In these devices, the light source power meter are coupled through a fiber coupler. The presence of the coupler induces some additional uncertainties, mainly due to loss dependent on coupler polarization, which adds to the total uncertainty.

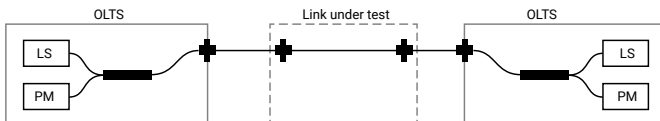


Figure 1. OLTS setup.

IDEAL LSPM VS. OTDR MEASUREMENTS

This section compares the fundamentals of LSPM and OTDR measurements.

LSPM loss measurement is performed in one direction (light travelling *forward*). The OTDR performs loss measurement by looking at the backscattering signal, which implies that light travels forward and backward in the fiber under test (i.e., OTDR pulses travelling forward and backscattering signal travelling backward). The OTDR then divides the measured loss by two to report the one-way loss.

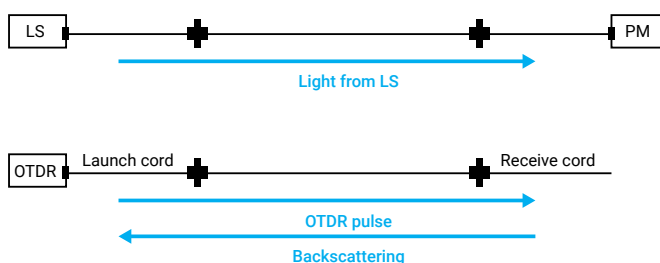


Figure 2. LSPM vs. OTDR.

In a singlemode optical fiber (SMF), a connection exhibits the same loss in one direction ($A \rightarrow B$) as in the other ($B \rightarrow A$). This is because SMF propagates only one mode: a single light beam. Therefore, the OTDR measurement process does not introduce any fundamental bias or error in comparison to an LSPM. **This means that if the measurements were ideal—i.e., taken using ideal instruments, under ideal test conditions and in an ideal setup—both the LSPM and OTDR would report the same loss value for any given singlemode link.**

The situation is different for multimode optical fibers (MMF). Given that fiber carries several modes, the loss measurement exhibits some directivity. For example, going from a 49 μm MMF to a 51 μm MMF will exhibit very little loss, while going from 51 μm MMF to 49 μm MMF will very likely exhibit some loss.

The LSPM performs loss measurement in one direction, while the OTDR injects light pulses with backscattering traveling back to it. Even if the OTDR is conditioned and EF-compliant (same conditioning as the light source), it is not possible to condition the backscattering signal. **This implies that some differences between the LSPM and OTDR loss measurements are to be expected since they are not fundamentally identical.** Some experimental data will be shown in the following sections.

OTDR THEORETICAL UNCERTAINTIES

The OTDR is a more complex instrument than the light source power meter setup. Calculating uncertainties in a theoretical way is therefore much more challenging. The following section details the main uncertainty contributors.

OTDR specification

In general, the OTDR does not have a specification for loss uncertainty; the reason why is explained in this section. Most OTDRs specify a loss linearity value.

Unfortunately, the definition of loss linearity, and how to measure it, is not standardized, so different OTDR manufacturers may use different internal definitions. In the case of EXFO's OTDRs, loss linearity is verified on a section of fiber generating approximately 0.5 dB loss, which is a stringent condition. The linearity specification of EXFO's FTB-7000C series is ± 0.03 dB/dB.

One could be tempted to multiply the linearity specification by the nominal loss to predict loss uncertainty (e.g., if the DUT shows a 10 dB loss, calculated uncertainty is $10 \text{ dB} \times 0.03 \text{ dB/dB} = 0.3 \text{ dB}$). Experimental data has shown that this is not true and this calculation tends to be too pessimistic for large loss but too optimistic for small loss.

We do not recommend trying to predict loss accuracy based on linearity specification.

Launch and receive test cord fiber geometry

It is well known that fiber geometry (mainly core size and the numerical aperture of the fiber) influences the amount of backscatter signal generated. This phenomenon causes some uncertainty in the OTDR measurement of individual connectors and splices loss. The industry recognizes an uncertainty contribution due to fiber geometry mismatch of ± 0.19 dB for SMF, assuming a typical fiber core specification of (9.2 ± 0.4) μm .

It can easily be demonstrated that the contribution of fiber geometry uncertainty is the same for the total link loss measurement. This is because the total link loss is dependent only on the geometry mismatch between the launch test cord fiber and the receive test cord fiber; in other words, the individual connector uncertainties do not add up—in fact, they cancel each other out. This specification is valid for a random set of launch and receive test cords. Using launch and receive test cords manufactured from the same fiber spool further decreases the practical uncertainty due to the geometry mismatch.

Finally, it is also widely known within the industry that the error due to fiber geometry can be removed by performing bidirectional OTDR measurements (i.e., take two OTDR measurements—one from end A and another from end B—and then average them). This approach eliminates any error due to fiber geometry variation for both individual connectors and splices, as well as for link loss.

“REAL LIFE” OTDR UNCERTAINTIES

OTDR trace noise

The quality of OTDR measurements depends on the proper adjustment of OTDR test parameters: pulse length, distance range and averaging time. A test done with a very short pulse and a short averaging time may yield an OTDR trace with significant noise. Noisy OTDR traces will exhibit poor repeatability, which will increase uncertainty.

Accordingly, the OTDR settings and the length of the receive fiber must be chosen with care to produce repeatable results.

Trace recovery

One of the most challenging test conditions for the OTDR is to measure the weak backscattering signal after a strong reflectance. The OTDR typically exhibits slow recovery following a strong reflectance. When strong reflectance occurs close to the end of the link under test, it may cause some error on the backscatter measurement on the receive test cord.

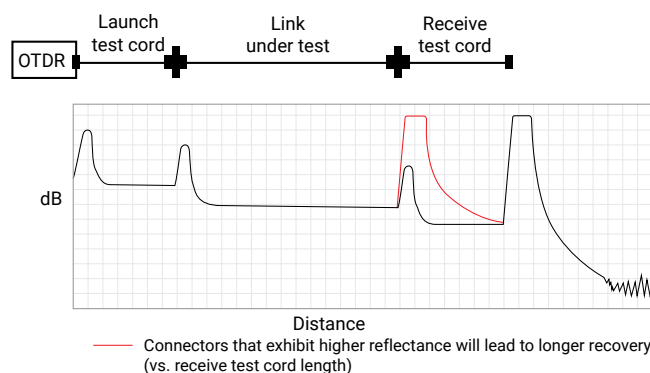


Figure 3. OTDR trace recovery.

Proper measurement of link loss requires sufficient receive test cord length. Minimum receive test cord length depends on the worst case scenario of reflectance that can be expected. Minimum receive test cord as a factor of reflectance varies depending on the OTDR manufacturer and model; as such, some pretesting is required to specify the optimal receive test cord length.

Trace analysis/event detection robustness

In general, OTDR performance is highly dependent on the quality of the raw OTDR trace (clean trace, no distortion or artefacts) as well as the robustness of the algorithms performing trace analysis (event detection and characterization).

Predicting OTDR uncertainties?

It is difficult to predict the loss measurement uncertainty of an OTDR based on its specification sheet. Unlike the LSPM, OTDR loss measurement uncertainty cannot be derived from typical uncertainty contributors since too much variability exists between OTDR models and manufacturers. Moreover, uncertainty also depends on the nature of the link under test (length, loss and reflectance). Accordingly, it is recommended that OTDR uncertainty be carefully evaluated for a given OTDR model, under specific test conditions and for a given set of link parameters.

SIMPLE TEST PROCEDURE FOR OTDR AND LSPM COMPARISON

To avoid introducing errors and bias to the results, it is important to perform the tests rigorously when comparing LSPM and OTDR. This section provides guidelines on how to best compare them.

For an EXFO OTDR, we recommend using the iOLM mode due to its multipulse technology. Its benefits include highly advanced acquisition and analysis, automation and ease of use—no settings are required, and the interpretation of the results is simpler and without risk of human error.

To avoid uncertainties related to the connectors' mating loss reproducibility, it is strongly recommended to use brand new reference grade launch and receive test cords. In the case of SMF measurement, a launch test cord of at least 15 m must be used. In the case of MMF measurement, the launch test cord must also include an EF conditioning device.

The following procedure is for MMF testing using an SPBS-EF device from EXFO.

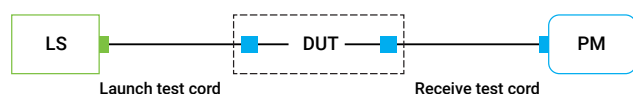
Step 1. LS power reference

- › Power ON the light source and allow sufficient warm-up time (typically 15 minutes)
- › Connect the light source (LS) and power meter (PM) together by using a suitable launch test cord (reference-grade test jumper; 2 to 3 m long)
- › For MMF, it may be required to condition the signal for EF compliance. Some products, like the MAX-940, have built-in internal EF conditioning and do not require external conditioning
- › Perform the reference power measurement (P0)



Step 2. Loss measurement for LSPM

- › Disconnect the launch test cord from the PM and connect it to the device under test (DUT)
- › Bring the PM to the other side of the network and use a suitable receive test cord (reference-grade test jumper, 2 to 3 m long) between the DUT and the PM
- › Perform loss measurement using the PM

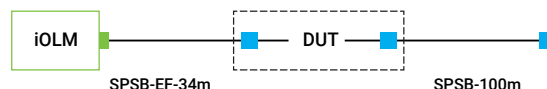


Step 3. Test other DUT

- › Repeat Step 2 for as many DUTs as needed

Step 4. iOLM IL measurement

- › Connect a suitable launch test cord between the iOLM and the DUT input
 - › For SMF, 15 m or more is required
 - › For MMF, a specific launch test cord that includes EF conditioning is required (SPSB-EF-34)
- › Connect a suitable receive test cord at the DUT output
 - › For SMF, 150 m is sufficient for attenuation up to 5 dB. Longer receive test cords are needed for larger losses
 - › For MMF, 100 m is recommended (SPSB-100) to avoid trace recovery following large reflections that may be found in the DUT
- › Specify the launch and receive test cords lengths in iOLM
- › Launch an iOLM acquisition and read the span loss.



To reduce measurement uncertainty related to fiber geometry in the iOLM test, it is important to use the same fiber type, manufacturer and model for launch and receive test cords. This is why EXFO takes extra care to specify tight fiber geometry tolerances for the test cords (SPSB) to minimize errors due to fiber geometry.

Step 5. Test other DUTs

- › Repeat Step 4 for as many DUTs as needed

Loss spectral dependency of fiber

The fact that the LS and the iOLM can have slightly different nominal wavelengths will cause some deviation in the measurements due to the spectral attenuation characteristics of the fiber. In general, connectors and splices losses have low dependencies on nominal wavelength, but not the fiber.

The following table shows the nominal loss and the loss variation for 20 nm change on the source wavelength.

Nominal λ (nm)	DUT	Nominal loss (dB)	Loss variation (dB) for nominal λ + 20 nm
850	350 m MMF (OM2)	0.84	-0.07
1300	350 m MMF (OM2)	0.21	-0.01
1310	10 km SMF	3.3	-0.22
1550	10 km SMF	1.9	-0.03

Table 2. Nominal loss and loss variation w.r.t fiber optic and wavelength.

RESULTS FOR MULTIMODE FIBER LINKS

This experiment compares loss measurements performed with a LSPM and an iOLM for MMF DUT. The graphs below display the loss measurements taken.

Test conditions:

- › 3 LSPM kit: MAX-940 used in OLTS mode (one-cord reference) at 850 nm
- › 3 OTDR kit: FTB-720, used in iOLM mode at 850 nm
- › Each kit has its own launch and receive fiber to consider connector mating reproducibility
- › 28 different DUTs (ordered from small to large nominal loss)

Reproducibility between different OLTS

It is expected that different OLTS will produce slightly different results due to the following:

- › Variation in central wavelength of the LS
- › Variability (i.e., reproducibility + repeatability) for the loss of the mating between the launch test cord and the DUT
- › Variability (i.e., reproducibility + repeatability) for the loss of the mating between the receive test cord and the DUT
- › Slight difference in EF conditioning (even if all LS are compliant to the EF template)

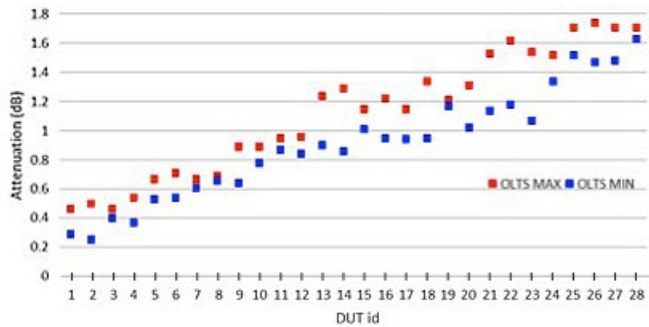


Figure 4. Reproducibility between 3 different OLTS with measurements at 850 nm.

Observations

- For any given DUT, the loss range (max – min) is coherent with the uncertainty of the LSPM method discussed earlier in this document.
- Maximum loss measurement does not always originate from the same OLTS kit; it seems to be quite random, as is the case for minimum loss. This indicates that connector mating loss dominates as the main source of uncertainty for this round of tests.

Reproducibility between different iOLM

It is to be expected that different OTDRs equipped with iOLM will produce slightly different results. The following figure shows the variability obtained with the three iOLM-OTDR kits.

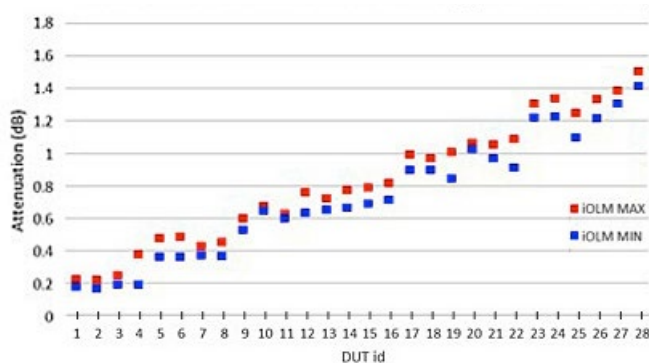


Figure 5. Reproducibility between 3 different iOLM-OTDR kits with measurements at 850 nm.

We observe a small deviation between the different iOLM-OTDR kits. This supports the previous observation that the iOLM shows high consistency between various units.

Deviation between OLTS and iOLM

To compare the OLTS to the iOLM, the following graph plots average OLTS measurements between three OLTS sets, and average iOLM measurements for each DUT.

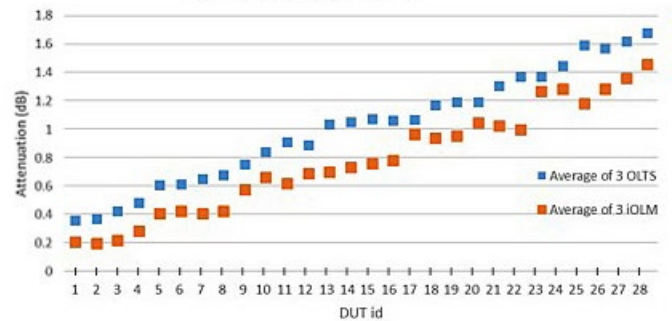


Figure 6. Deviation between OLTS and iOLM with measurements at 850 nm.

We can observe a small systematic bias between the iOLM and the OLTS. This small bias (around 0.25 dB) is due to the fundamental backscattering process which produced an underfilled equivalent measurement for the iOLM even if the iOLM is EF-compliant.

RESULTS FOR SINGLEMODE FIBER LINKS

The measurement of loss on a singlemode fiber link is expected to yield the same results for the LSPM setup and the OTDR. Accordingly, the experiment that has been performed is to compare an OTDR with an ideal LSPM setup, considered as being a reference measurement. The graph below displays the loss deviation (LSPM loss – iOLM loss) vs the reference loss (LSPM loss).

Test conditions

- Five OTDR samples: FTB-730C, used in iOLM mode
- PM was a laboratory-grade device to get the best reference possible
- LS was derived from the OTDR source in CW mode (using a custom setup to improve stability) to eliminate deviations due to fiber spectral dependency
- Same reference launch and receive test cords were used for LSPM and iOLM, for no deviation related to connector mating loss reproducibility. LSPM loss is then corrected to compensate for the receive test cord length
- Five launch test cords (30 m) and five receive test cords (150 m for DUT < 5 dB and 500 m for DUT > 5 dB). Launch and receive fibers are from the same manufacturer and model but from different batches to take into account fiber geometry variation
- DUT were different assemblies of fibers with loss varying between 1 dB and 12 dB
- No bidirectional averaging was performed

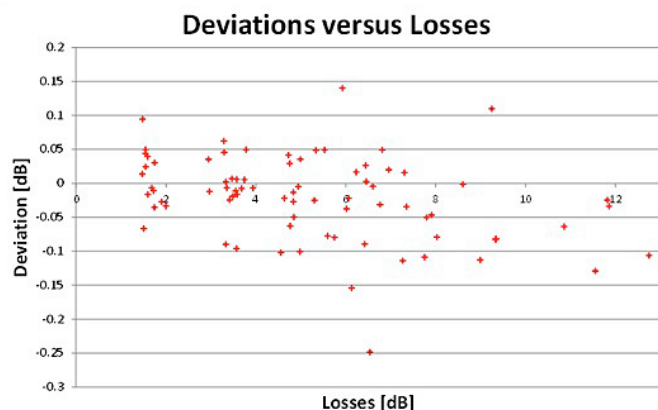


Figure 7. iOLM-OTDR SMF deviations vs. losses.

RESULTS

These results demonstrate that the iOLM can measure insertion loss that is very close to a reference measurement, with a deviation that is below 0.25 dB and without systematic (average) bias.

Direct comparison between the iOLM-OTDR and the LSPM using a test procedure like the one used for MMF will typically yield slightly larger differences; this is because the iOLM and the LS are two different units and their nominal wavelengths will be slightly different (each unit typically has a ± 20 nm central wavelength specification). Moreover, the connection to the DUT will be different since different launch and receive test cords are used for the OTDR and the LSPM.

SUMMARY

We demonstrated good agreement between the OTDR (using the iOLM software) and the light source power meter (LSPM) setup for the measurement of end-to-end insertion loss measurement. For multimode fiber, a small bias was found between the OTDR and the LSPM due to the OTDR backscattering process. For singlemode fiber, there is no bias between the OTDR and the LSPM.