093

EVALUATING IL MEASUREMENT UNCERTAINTY DURING CONNECTOR AND CABLE-ASSEMBLY TESTING

APPLICATION NOTE

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Fiber-optic connectors are getting better and better. From an optical performance point of view, this means that both connector insertion loss (IL) and reflectance levels are getting lower. Obtaining better reflectance measurements, of course, requires sensitive and accurate reflectance measurement capability, while testing low-loss connectors requires accurate and stable IL measurement capability (for more detailed information on reflectance measurements, please refer to Application Note 90, *Sensitivity and Repeatability for Measuring Reflectance Drift in Fiber-Optic Connectors*). This application note explains how to evaluate the IL measurement accuracy of your test equipment and describes the different sources of error that affect measurement results.

IL is a relative measurement for which reference standards are very difficult (if not impossible) to obtain. Even if standards were available, the additional uncertainty caused by connecting or splicing in the reference unit would render the standards useless, especially for very small IL values. This is why metrology specialists recommend using a theoretical approach to determining IL measurement uncertainty.

Many singlemode cable-assembly manufacturers are now guaranteeing a maximum loss of 0.25 dB, 0.2 dB or even better with “tuned” connectors–an exceptional performance. Testing these connectors requires specialized equipment along with a thorough understanding of the possible sources of error. Recognizing and understanding these sources of error is extremely important so as to help you adopt test procedures that will minimize their effects.

A basic IL measurement is a relatively simple procedure that requires a light source and a power meter. There are different types of light sources and different types of power meters, as well as multiple variations on the exact procedure. However, in all cases, the objective is to compare measurements made with the device in-circuit, to measurements made with no device (reference measurement).

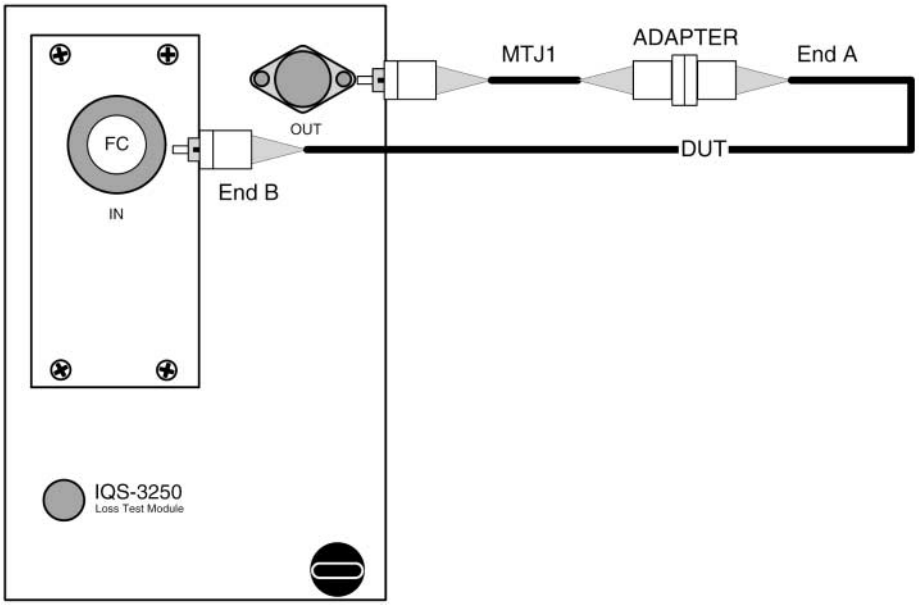

Figure 1. Schematic for IQS-12001B simplex connector testing

The factors that influence IL measurement uncertainty depend on the system and on the device configuration. For example, a simple measurement would consist in the configuration shown in Figure 1–a typical setup for testing simplex cable assemblies with EXFO's IQS-12001B Cable Assembly Test System. The following are the main sources of error for this type of measurement:

- Power meter linearity
- Power meter polarization-dependent responsivity (PDR)
- Power meter connection repeatability
- Source stability
- Power meter resolution

During the optical qualifications of the IQS-12001B system, EXFO engineers characterized each of these parameters; therefore, the specifications published on the IQS-12001B data sheet take these factors into account. Although other instrument vendors do not necessarily use this approach, the information presented below will allow you to make the same analysis on any test equipment.

Power Meter Linearity

Power meter or loss meter linearity is a measure of the relative accuracy of the instrument. For measuring IL, which is a relative measurement, this is obviously very important. For example, if you measure 0.000 dBm and then reduce the power by exactly 1.000 dB, what will the instrument measure? If there is no linearity error, it will measure exactly –1.000 dBm. This specification depends to a large degree on the electronics design, on the calibration technique used for the instrument, as well as on the power range of intended use. The best power meters available have a linearity error of approximately ± 0.010 dB, compared to ± 0.05 dB or higher for non-optimized instruments.

There are several ways to accurately measure linearity–a standard measurement in EXFO's IQ-12002 Optical Calibration System (for more information, visit http://www.exfo.com/en/products/gf_Product106.asp). Your instrument vendor should be able to supply linearity information and specifications, as well as supporting data and the procedure used.

The power meter included with the IQS-12001B system is designed around EXFO's IQS-1600 High-Speed Power Meter series, which has a linearity specification of 0.015 dB over the extended power range of –55 dBm to 0 dBm. During typical use, the IQS-12001B system operates at about –35 dBm and the range is very small (connector losses from 0 to 1 dB). Under these conditions, the non-linearity of the power meter is lower than the worst-case specification; nevertheless, in the system error analysis, the worst-case value of 0.015 dB should be used.

Power Meter Polarization-Dependent Responsivity (PDR)

All detectors and detector assemblies are polarization-dependent to some degree. This means that even though the input power is kept stable, the power meter response may change as the state of polarization (SOP) changes. Unless a compensation technique is used, wide-area InGaAs detectors are particularly sensitive, whereas integrating cavities usually have very low PDR. Detector PDR can vary from 0.005 dB to 0.030 dB or even higher. You will see below that this is an important specification, yet not often considered in the error analysis for cable assembly test systems.

The sources used for measuring IL of singlemode connectors are most often laser sources, which are highly polarized. When handling or moving a singlemode fiber that transmits a polarized light source, the state of polarization of the transmitted lightwave changes. If you have a detector with inherent polarization sensitivity, you will observe that the power reading will change. The magnitude of this change will depend on the PDR of the detector, and on how much the polarization has changed. When measuring connector IL, the fiber is being continuously handled. Therefore, it is easy to see how this can affect IL measurement uncertainty.

An IL measurement is taken in two steps: a reference measurement and a DUT measurement. At either one of these steps, the measurement is taken somewhere between the minimum and maximum boundaries of the detector's PDR; therefore, the error is applied twice (± PDR/2). This is a significant possible source of error but, in practice, the probability of ever experiencing the worst-case error is quite small.

A simple way to verify the polarization sensitivity of any particular setup is to move the fiber while it is connected to the detector and to observe the variations. Ideally, a polarization controller should be used. However, should you not have one, moving the fibers in a way similar to the typical manipulations that occur when handling cable assemblies will give you an excellent idea of the PDR value that you should input into your overall uncertainty calculation.

The IQS-12001B detectors use an integrating cavity, whose PDR has been evaluated at a worst-case value of 0.020 dB. For this reason, the calculation sheet below includes two Power Meter PDR lines of ± 0.010 dB. Performing the test described above, you will likely observe a much smaller variation.

Power Meter Connection

This factor is an evaluation of the repeatability of the connection on the detector. As simple as the fiber-optic adapter (FOA) appears, developing repeatable connector-to-FOA coupling is a complex design problem that needs to address many of the following parameters:

- Available detector surface area
- Uniformity of detector responsivity
- Mechanical tolerances of connectors and ferrules
- Position repeatability
- Distance from ferrule endface to detector surface
- Numerical aperture of fiber
- The type of fiber
- Anti-reflection coatings
- Multipath interference from multiple reflective surfaces (detector, window, ferrule endface, backside of FOA)

To properly evaluate this error contribution, non-polarized light is used so that the influence of the PDR is minimized. Appropriate light sources would include an ASE source or a surface-emitting LED source. If these are not available to you, simply disconnecting and reconnecting the connector from the detector a few times will give you a very good idea of the connection repeatability, especially if you take care not to change the routing of the fiber. While doing this, record the maximum and minimum value. Enter ± delta/2 (where delta = maximum value – minimum value) in the calculation table.

The IQS-12001B uses a detector assembly incorporating an integrating cavity. This design provides very important advantages with respect to connection repeatability. For the IQS-12001B, the connection repeatability has been evaluated at ± 0.010 dB.

Source and System Stability

The optical power of any light source will vary with time and environmental conditions. When relying on a stored reference value, any change in the power of the source (since the reference was taken) will create a direct error on the resulting measurement. Depending on the test system design, some sources are turned on and left on, and others are rapidly switched on and off. Some designs use opto-mechanical switches to switch back and forth between wavelengths, and others use a monitoring detector to measure the source power for each measurement. Whichever method is used, a certain amount of measurable drift will occur, having a direct impact on the measurement uncertainty.

Regardless of your system's design, the best way to evaluate drift and instability is to connect a master test jumper to your detector and perform a reference measurement. Do not disturb any of the fibers (not to modify the state of polarization) or disconnect any of the cables or patchcords. After some time, perform an IL measurement at both wavelengths (or more, if applicable). It is important to check all wavelengths since this is what you will be testing most often in production. Any deviation from a loss of 0.000 dB is representative of your system's stability error. If you wait a few hours and produce temperature changes similar to those in your production environment, you will clearly see the drift in the measurement. Enter ± delta/2 in the calculation table.

The IQS-12001B uses an internal reference detector to compensate for any source power drift. Nevertheless, the system allows for a possible error contribution of ± 0.01 dB, including the small linearity error of the internal detector (always reading nearly the same power), as well as coupling ratio variations of the monitoring coupler.

Although it is not always convenient to perform frequent reference measurements, stability errors can be greatly minimized by doing so.

Power Meter Resolution

In order to completely and thoroughly perform an uncertainty analysis, you must also take into consideration the display resolution. This is simply the rounding off of the calculated result; yet, when pushing the performance envelope, it must be included. The uncertainty contribution of rounding up or down is taken as half of the display resolution.

Calculating the Uncertainty Value

	Error Source	**Uncertainty**	**Probability Distribution**	**Divisor**	**Standard Uncertainty**	**Sensitivity Coefficient**	**Uncertainty Contribution**
i	X_i	**(dB)**			$u(x_i)$	c_i	$u_i(y)$ **(dB)**
1	Power Meter Linearity	0.0150	Rectangular	1.7321	0.0087	1.0000	0.0087
2	Power Meter PDR	0.0100	Rectangular	1.7321	0.0058	1.0000	0.0058
3	Power Meter PDR	0.0100	Rectangular	1.7321	0.0058	1.0000	0.0058
4	Connection	0.0100	Rectangular	1.7321	0.0058	1.0000	0.0058
5	Source Stability	0.0100	Rectangular	1.7321	0.0058	1.0000	0.0058
6	Power Meter Resolution	0.0050	Rectangular	1.7321	0.0029	1.0000	0.0029
y						Combined Uncertainty	0.0147

Coverage Factor	k =	2.0000
Expanded Uncertainty	U =	0.0294

In the above table, each of the factors previously described is listed along with its uncertainty. Depending on the observed (or theoretical) distribution of the error, a divisor is applied so that a standard uncertainty value for each error source can be calculated. For a rectangular distribution, this divisor is $\sqrt{3}$; for a normal distribution, the divisor is 2; and for a U-shaped distribution, the divisor is $\sqrt{2}$. The uncertainty contribution for each error source is the product of the sensitivity coefficient and the standard uncertainty. The total uncertainty is calculated as the root of the sum of the squares of the individual uncertainty contributions. The expanded uncertainty is calculated by multiplying the total uncertainty by the coverage factor k. With $k = 2$, the level of confidence is about 95 %.

It should be clear that the above evaluation of the loss measurement uncertainty is both very thorough and reasonably conservative. The values shown are for the EXFO IQS-12001B Cable Assembly Test System. As indicated in the next paragraph, in everyday use, you should observe performance better than the guaranteed 95 % confidence level specification of ± 0.030 dB.

For example, during an evaluation, or while developing a high-accuracy test method, you may discover that the polarization sensitivity of the detector, under normal conditions of use (the way the patchcords are moved during tests), appears to be negligible. In addition, since the losses being measured are very close to 0.0 dB, the detector linearity error may also be considered negligible; thus, the expanded uncertainty for the test system under these particular conditions can be recalculated, as in the table below.

i	**Error Source** **X_i**	**Uncertainty Distribution (dB)**	**Probability**	**Divisor Uncertainty**	**Standard Coefficient** **$u(x_i)$**	**Sensitivity Contribution** **c_i**	**Uncertainty** **$u_i(y)$ (dB)**
1	Power Meter Linearity	0.0150	Rectangular	1.7321	0.0087	0.0000	0.0000
2	Power Meter PDR	0.0100	Rectangular	1.7321	0.0058	0.0000	0.0000
3	Power Meter PDR	0.0100	Rectangular	1.7321	0.0058	0.0000	0.0000
4	Connection	0.0100	Rectangular	1.7321	0.0058	1.0000	0.0058
5	Source Stability	0.0100	Rectangular	1.7321	0.0058	1.0000	0.0058
6	Power Meter Resolution	0.0050	Rectangular	1.7321	0.0029	1.0000	0.0029
y						Combined Uncertainty	0.0087

Under these conditions, the calculated expanded uncertainty is now less than 0.02 dB, with a 95 % confidence level (please note that the sensitivity coefficient for the first three error sources in the table was set to 0). Further improvements to the measurement can be made by performing periodic reference measurements to reduce the source stability uncertainty contribution or by hand-selecting a more repeatable FOA adapter.

More Complex Applications

The uncertainty analysis presented up to this point addresses a simple system for testing simplex cable assemblies. For multifiber assemblies, additional switches and different types of adapters are typically used to connect to the power meter.

For the switches, it is important to evaluate the insertion loss repeatability and the effect of the switch's PDL. IL repeatability is easy to estimate by simply measuring the loss over numerous cycles under typical conditions while minimizing any movement of the fibers. Evaluating the effect of the switch's PDL is a little more difficult. Using the switch's PDL specification will give you a worst-case value, but will tend to over-estimate the influence, especially if the fiber connection between the source and the switch is held mechanically stable. Enter the values in the calculation table and recalculate system uncertainty.

For multifiber assembly testing, the effect of the non-uniformity of the wide-area detector must also be evaluated and included in the overall uncertainty calculation. This is especially important when referencing in the middle of the detector and measuring away from the center, as would be the case during hybrid-fanout-assembly testing. Without specialized alignment jigs or adapters that allow you to move the active fiber across the detector surface, this evaluation is difficult to make. Some wide-area detectors are more uniform than others, and this can vary with suppliers and wafer batches. Detectors with guaranteed uniformity do exist, but without question, an integrating cavity such as that used by the IQS-12001B offers superior overall performance.

Conclusion

Although specific to cable assemblies, much of this information can be applied to any loss measurement system and, in a broader sense, should provide basic understanding of how instrument measurement uncertainties are calculated. The techniques and calculation methods described in this application note comply with the recommendations given in the Guide to the *Expression of Uncertainty in Measurement (GUM), BIPM, IEC, ISO, IUPAC, IUPAP, OIML, 1st edition, 1993*.

It is unfortunate that instrument vendors do not always evaluate measurement uncertainties in the same way, which is important to keep in mind when comparing products. By asking the right questions and/or performing a few experiments, you should be able to come to your own conclusions as to which equipment is suitable for the job at hand.

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