Passive component characterization:

main specifications for filters and broadband components

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About EXFO

EXFO develops smarter test, monitoring and analytics solutions for the global communications industry. We are trusted advisers to fixed and mobile network operators, hyperscalers and leaders in the manufacturing, development and research sector. They count on us to deliver superior visibility and insights into network performance, service reliability and user experience. Building on our 35 years of innovation, EXFO's unique blend of equipment, software and services enable faster, more confident transformations related to 5G, cloud-native and fiber optic networks.

Introduction

A wide variety of passive optical components can be found nowadays, whether they are deployed in the field, in modules or benchtop instruments. The following is a non-exhaustive list: wavelength division multiplexing (WDM) filters, reconfigurable add-drop multiplexers (ROADMs), switches, couplers and Fabry-Perot wavelockers. Component characterization represents a crucial step in manufacturing, quality control, incoming inspection and later during the component's life. The characterization method that best suits the needs will depend on the specifications that need to be measured, the wavelength range of interest as well as the desired speed, accuracy or sampling resolution.

This document gives an overview of the main specifications of interest for two types of passive components: filters and broadband components. Three common characterization methods will be discussed using either a broadband source or a tunable laser source (TLS).

IL, RL, PDL measurements

Most of a component's specifications are calculated either from insertion loss (IL), return loss (RL) or polarization dependent loss (PDL). Insertion loss represents the optical loss through a device under test (DUT) and is usually expressed in optical decibels (dB). Return loss represents the proportion of the light reflected by the component, whereas polarization dependent loss characterizes the maximum variation of the insertion loss across all possible polarization states. IL, RL and PDL can be single values measured at a given wavelength or refer to a measurement made across a wavelength range.

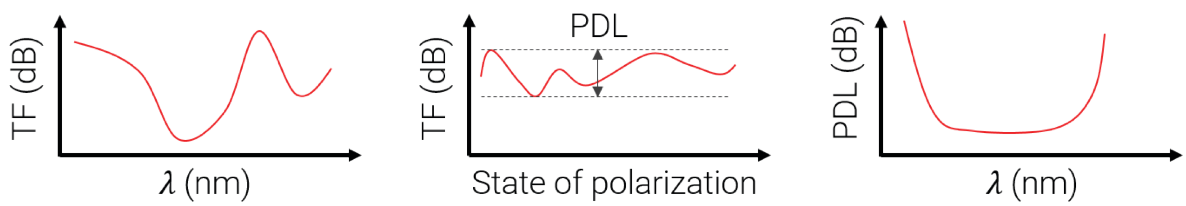

Figure 1. Schematic representations.
(left): Transfer function measurement (IL versus wavelength).
(middle): PDL measurement at a given wavelength using the all-states method.
(right): PDL measurement versus wavelength.

Reference formalism

IL and RL measurements are typically part of a two-step procedure to eliminate undesired contributions and ensure accurate and consistent results. A reference measurement should be taken first without the DUT, followed by a measurement with the DUT. An example of the basic formalism applied to an IL measurement is detailed below.

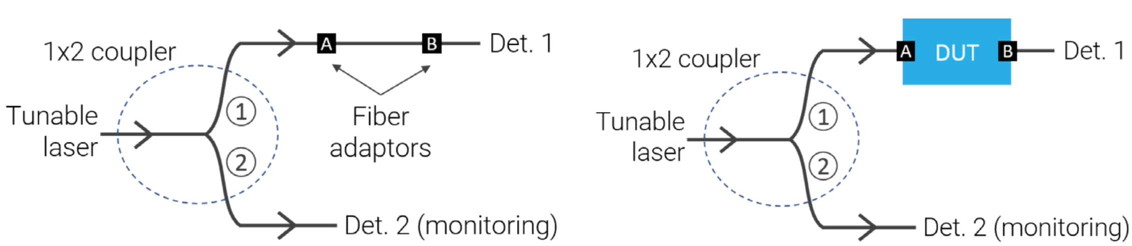

Figure 2. Two-step testing procedure.
Step 1 (left): reference measurement without the DUT. Step 2 (right): measurement with the DUT.

$$Measurement\ with\ the\ DUT_{(dB)} = 10\ log_{10}\left(\frac{P_{Det1}}{P_{Det2}}\right) = 10\ log_{10}\left(\frac{TF_1 \, . \, TF_A \, . \, TF_{DUT} \, . \, TF_B}{TF_2}\right)$$

With

TF_1 and TF_2 the transfer functions of both arms of the optical coupler.

TF_A and TF_B the transfer functions of the optical adaptors, respectively A and B.

TF_{DUT} the transfer function of the DUT.

In addition to the DUT’s transfer function, we can see that the calculation also contains terms coming from the coupler (TF1 and TF2) as well as the fiber adaptors (TFA and TFB) used to connect the DUT. A reference measurement allows to remove the influence of these terms. It should be noted that the reference measurement is useful even when using a calibrated coupler because its transfer function may vary over time (e.g., with temperature). The monitoring power meter (Det. 2) is used to compensate any power fluctuation of the optical source during the measurement.

$$Reference_{(dB)} = 10\ log_{10}\left(\frac{P_{Det1}}{P_{Det2}}\right) = 10\ log_{10}\left(\frac{TF_1 \, . \, TF_A \, . \, TF_{fiber} \, . \, TF_B}{TF_2}\right)$$

With

TF_{fiber} the transfer function of the fiber used during the reference measurement.

Finally, the transfer function of the DUT can be calculated:

$$IL_{DUT(dB)} = Measurement\ with\ DUT_{(dB)} - Reference_{(dB)} = 10\ log_{10}\left(\frac{TF_{DUT}}{TF_{fiber}}\right)$$

Reference measurements are essential for IL and RL measurements. A reference trace does not necessarily need to be performed before each measurement but rather on a daily basis or after any change in the experimental setup or conditions. PDL measurements made with the all-states method use relative power variations and not always benefit from a prior reference measurement.

Passive components

Filter type components

Whether they are broadband such as CWDM (de)multiplexer or single/dual band in the case of DWDM, filter type DUTs often have several channels for which the following characteristics need to be measured:

- Peak wavelength and IL at this wavelength
- Wavelength offset versus ITU grid
- -1 dB, -3 dB and -20 dB widths
- Adjacent and non-adjacent isolation
- Flatness and ripple
- PDL
- Roll-off between -3 dB and -20 dB

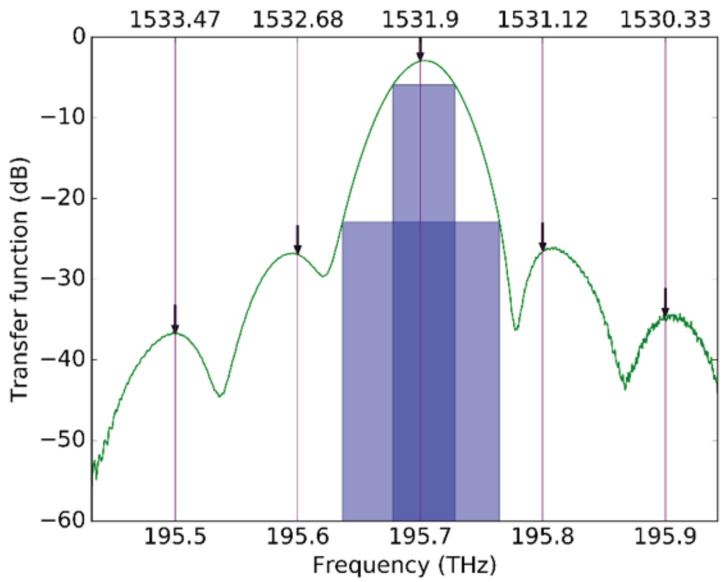

Figure 3. Characterization of the channel 57 of a 100 GHz DWDM demultiplexer. Vertical lines represent the 100 GHz ITU grid. Black arrows represent points of interest. Blue rectangles show the -3 dB and -20 dB windows.

λ peak	1531.865 nm
IL @ λ peak	-2.91 dB
λ offset vs grid	-0.033 nm
IL @ λ grid	-2.97 dB
Width @ -1 dB	0.226 nm
Width @ -3 dB	0.396 nm
Width @ -20 dB	1.002 nm
Adjacent channel	
Min. isolation	26.54 dB
Max. isolation	26.91 dB
Non-adjacent channel	
Min. isolation	34.65 dB
Max. isolation	36.76 dB

Broadband components

Components that have a small dynamic range (i.e., small variations of their transfer function) include couplers, switches and attenuators. These components typically operate over a very wide wavelength range, sometimes from the O up to the L telecom band. The parameters of interest can be:

- IL and IL flatness
- Ripple of the transfer function
- PDL and return loss

An overview of three different approaches for passive component characterization is given in the next sections. Main advantages and limitations are discussed in relation to the requirement previously discussed.

Characterization methods

Optical spectrum analyzer

Superluminescent diodes (SLED) and ASE light sources are broadband light sources that can be used in conjunction with an OSA to perform IL measurement. Although this method provides fast IL measurement, it only allows to test one DUT output at a time and does not enable RL or PDL measurement. The limited dynamic range resulting from the low power spectral density of the light source tends to be a limiting factor, particularly as we move away from the source's central wavelength.

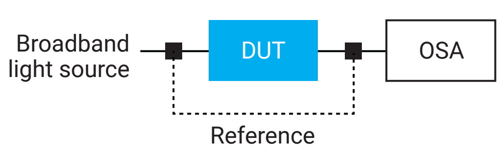

Figure 4. Typical configuration for IL measurement using a broadband light source and an OSA.

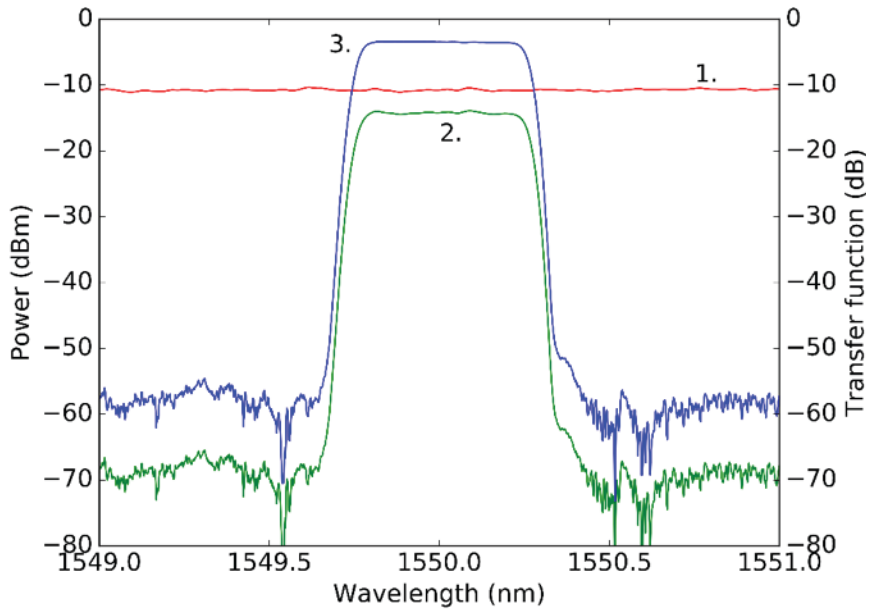

Figure 5. Filter characterization using a broadband light source and an OSA. Reference trace without the DUT (1. in red, left scale), trace with the DUT (2. in green, left scale), and transfer function (3. in blue, right scale).

Additionally, the power measured by the OSA corresponds to the power spectrum seen through the OSA's monochromator. Signal distortion caused by the monochromator cannot be ignored as the bandwidth of the DUT approaches the OSA's optical bandwidth or as the DUT's slope approaches the monochromator's slope (see Figure 6 below). These limitations are particularly relevant when measuring filter type components.

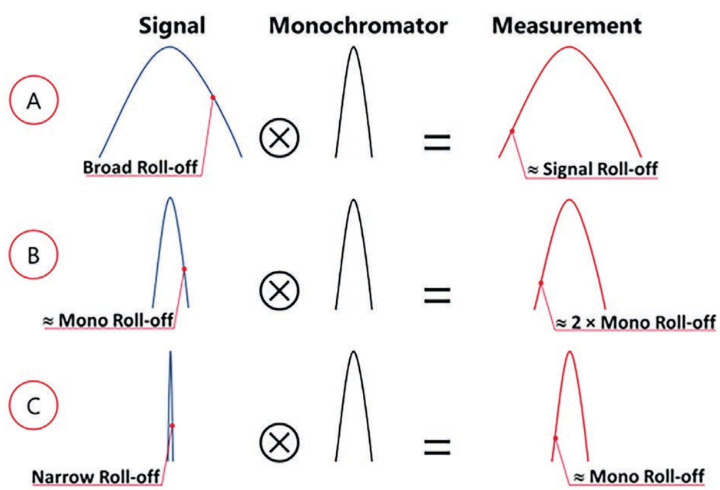

Figure 6. Schematic representation of the convolution between the signal and the monochromator shape.

Furthermore, it is difficult to implement real-time power monitoring of the source power when using an OSA, so care must be taken to avoid any power drift between the reference measurement and the measurement with DUT.

In conclusion, this method is particularly suitable for IL measurement of single output components with relatively low insertion loss and dynamic range. Taking advantage of the OSA's wide wavelength range, several broadband light sources can easily be combined to get a very cost-effective broadband solution providing high resolution and fast measurement time.

Tunable laser source

General considerations and source spontaneous emission influence

The monomode (single wavelength) nature of tunable lasers and the possibility to achieve high resolution are key features that make tunable lasers an essential tool for component characterization. However, there is a wide variety of tunable lasers with large differences in specifications.

External cavity lasers (ECL) have been widely used in test and measurement applications thanks to their wide tuning range (up to 200 nm), high resolution and fast tuning speed. On the other hand, single wavelength measurements can be made using distributed feedback (DFB) lasers which have a typical tuning range of 2 nm. These lasers are more cost-effective but do not offer the versatility nor the tuning range of external cavity lasers and are inadequate for wavelength dependent measurements.

Source spontaneous emission (SSE) that occurs in the active medium (laser diode) of all tunable lasers should also be considered. SSE creates a broadband optical emission that superimposes to the laser. With filter types components (e.g., fiber Bragg grating or multiplexer), part of this broadband optical noise goes through the passband section of the DUT and is detected by the power meter. The figure below illustrates how this artificially increases the measured transfer function.

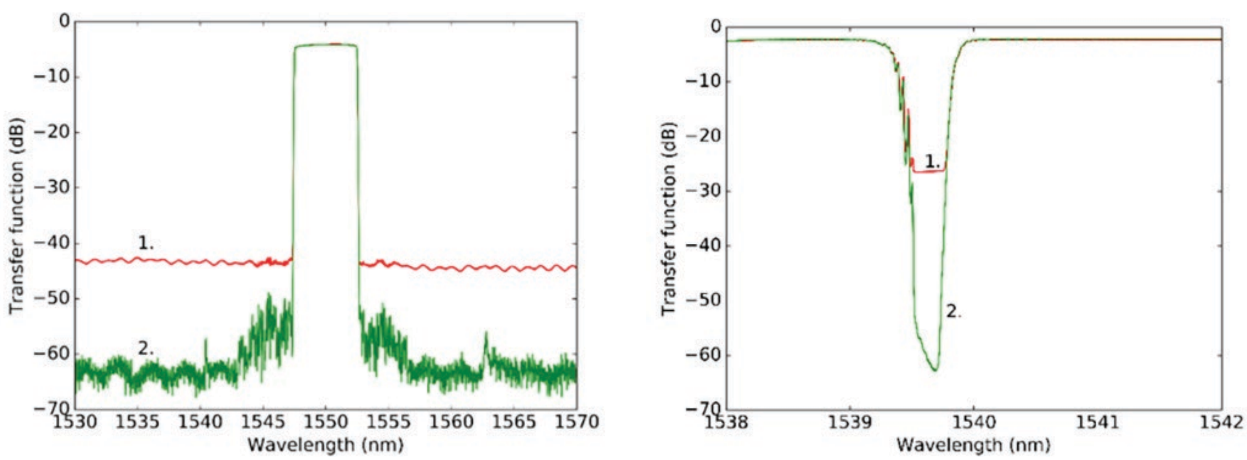

Figure 7. Characterization of a tunable filter (left) and fiber Bragg grating (right) with a high SSE laser (1. in red) and low SSE laser (2. in green).

Low SSE lasers rely on an improved cavity design that eliminates this broadband emission, therefore allowing high dynamic range measurements. The laser to SSE level is usually referred in the datasheets as signal to source spontaneous emission ratio (SSSER). Higher SSSER provides an increased dynamic range when measuring filter type components.

Step-by-step measurement

Step-by-step measurement using a tunable laser is a widespread method thanks to its simplicity, versatility and relatively low cost. The use of a power meter rather than an OSA makes the number of detector scalable to characterize simultaneously several channels of a component.

The *step and measure* approach offers a great flexibility in terms of possible measurements: IL and RL would usually be characterized using the setup shown in Figure 8 while PDL measurement can be performed using a polarization scrambler and the all-states methods (see Figure 9). When all the desired measurements are completed, the wavelength of the laser is remotely tuned to the next wavelength of interest. Additional equipment such as a wavemeter can be easily added to the setup to improve the measurement accuracy.

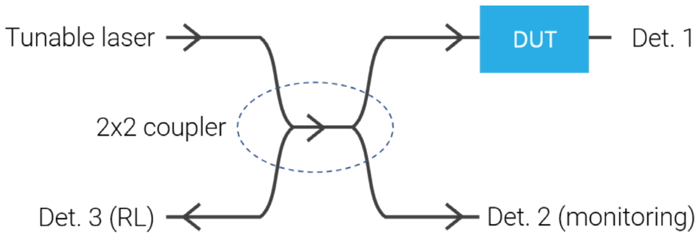

Figure 8. Typical IL and RL measurement setup.

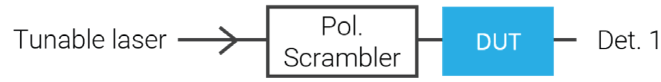

Figure 9. Typical step-by-step PDL measurement using a polarization scrambler and the all-states method.

The choice of wavelength resolution is a trade-off between accurately measuring the desired characteristics of the component while maintaining a reasonable measurement time. CWDM and broadband components can often be characterized in step-by-step because the wavelength resolution is usually larger than 100 pm.

However, the step-by-step approach gets extremely time-consuming when finer resolution or wider wavelength range is required. In those cases, swept measurements become more appropriate.

Swept measurement

During a swept measurement, the laser continuously moves across the wavelength range and a triggering system triggers one or several external instruments, usually power meters. As the laser does not stop at each wavelength where a measurement is taken, measurement speed is greatly improved compared to a step by step measurement. A measurement over a 100 nm span with picometer resolution typically takes a few seconds to complete. In those setups, sampling resolution and wavelength accuracy depend on the triggering system, whether it is integrated to the laser or external.

On one hand, IL and RL measurement setup does not differ from a step by step approach and can be performed with the setup shown in Figure 7.

On the other hand, PDL measurement requires special attention and a different method is used for PDL determination. A swept PDL measurement requires a polarization controller to perform successive scans with different well-known polarization states (usually 4 or 6). The PDL can then be calculated using Mueller calculus.

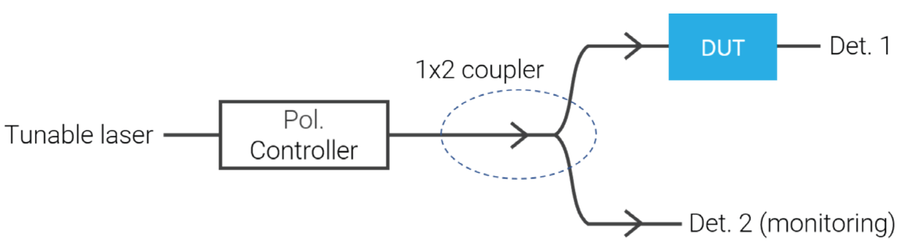

Figure 10. Typical swept PDL measurement using a polarization controller.

One key aspect of swept measurements is the more stringent requirements put on the laser and power meters compared to a step-by-step measurement. The tunable laser must be able to perform mode hop-free sweeps (without wavelength discontinuity) whereas the detector must be able to buffer a large number of data points within a short integration time and high dynamic range.

DWDM components typically require picometer resolution and benefit from the advantages of a swept measurement. Highly resolved and accurate measurements can be performed within seconds allowing high throughput in manufacturing.

EXFO’s solutions

OSA and broadband source

EXFO’s line of optical spectrum analyzers includes the FTBx-5245/5255 and OSA20. They can be combined with the FTBx-2250 broadband light source to perform transmittance measurement with dedicated analysis tools.

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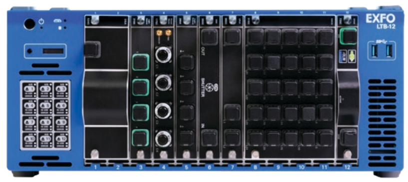

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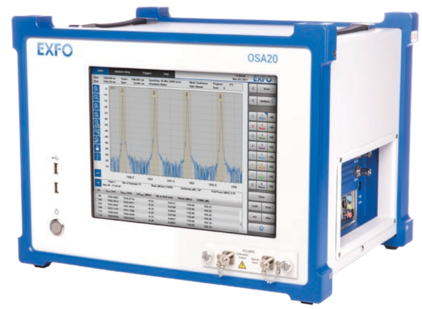

Laser – Step-by-step measurement

T100 laser modules are a compact, fast-tuning and cost-effective solution for step-by-step measurements. They fit in the OSICS platform and rely on a low-SSE (high SSSER) cavity design.

It is possible to integrate four T100 modules with a switch to cover the full wavelength range from 1260 nm up to 1680 nm in a single instrument with a 19-inch form factor. An LTB-8 platform with FTBx-1750 power meters can be used to set up a complete test system.

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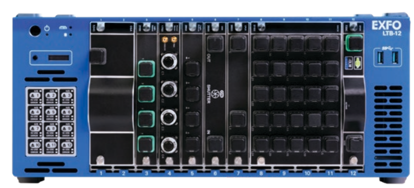

Laser – Swept measurement

Swept IL-RL measurements can be performed using the CT440 component tester or CTP10 platform. Both solutions leverage EXFO’s sweeping tunable lasers and use optical triggering to achieve high sampling resolution and accuracy at any speed. Additionally, several tunable lasers can be combined to further increase the wavelength range.

The CTP10 platform can host up to 50 power meters and is particularly suitable for high port count components.

Swept PDL measurements can be done using a CT440-PDL or the CTP10 platform together with the IL PDL series module.

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