

Insertion loss and return loss: relative measurements using the CTP10 platform

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Relative measurement

This application note explains the signification of the term “relative” when insertion loss (IL) and return loss (RL) are said to be relative measurements. In the context of optical testing, a measurement is said to be relative when the result obtained does not depend on the absolute power accuracy of the optical detectors used.

Optical detectors typically have a total power uncertainty of $\pm 5\%$ (± 0.2 dB). Since IL and RL measurements require two optical detectors—one for power monitoring and one to measure the transmitted or reflected power—the total measurement uncertainty has to take into account the uncertainty of both detectors, resulting in an even larger uncertainty.

Relative measurements rely on the fact that when a proper referencing procedure is followed, the power uncertainty of the detectors can be compensated, greatly improving the measurement uncertainty. The application note describes further below how this compensation can be achieved in the case of IL and RL measurements.

Definitions

IL and RL of a device under test (DUT) are defined as follows:

$$IL_{(dB)} = P_{incident (dBm)} - P_{transmitted (dBm)}$$
$$RL_{(dB)} = P_{incident (dBm)} - P_{reflected (dBm)}$$



Under this definition, IL and RL are positive numbers. With this sign convention, the pass-band region of a band-pass filter appears at the bottom of an IL (λ) graph, which may cause some confusion with a band-stop filter.

To remove this potential source of ambiguity, the CTP10 displays transfer function (TF) and backreflection (BR) results as negative values. The terms TF and BR are defined as follows:

$$TF_{(dB)} = -IL_{(dB)}$$

$$BR_{(dB)} = -RL_{(dB)}$$

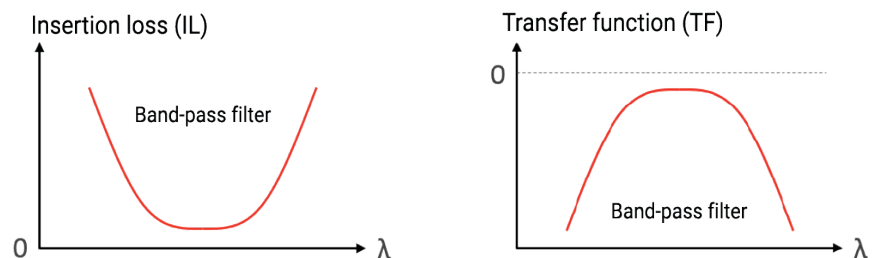


Figure 1. Schematic plot of the same passband filter using two different representations: (left) IL with a positive sign convention; (right) TF with negative results. The CTP10 uses the TF convention shown on the right.

Although not explicitly written, transfer function and backreflection are wavelength-dependent in the case of swept measurement.

Please note that the nomenclature below is followed in this application note:

- The terms denoted IL, RL, TF, BR and Shift are expressed in optical decibels (dB)
- The terms denoted P are expressed in dBm
- Superscripts and subscripts represent the detector and the measurement respectively

For instance:

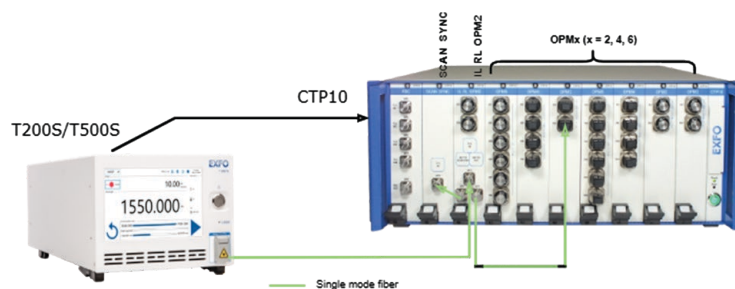
- P_{ref}^{OPM} represents the power measured on the optical detector after the DUT (OPM) during the reference measurement without DUT
- $P_{meas}^{monitoring}$ presents the power measured on the monitoring detector during the measurement with DUT
- $P_{bkg\ ref}^{RL}$ represents the power measured on the RL detector within the IL RL OPM2 module during the background noise reference measurement

Insertion loss

Terminology:

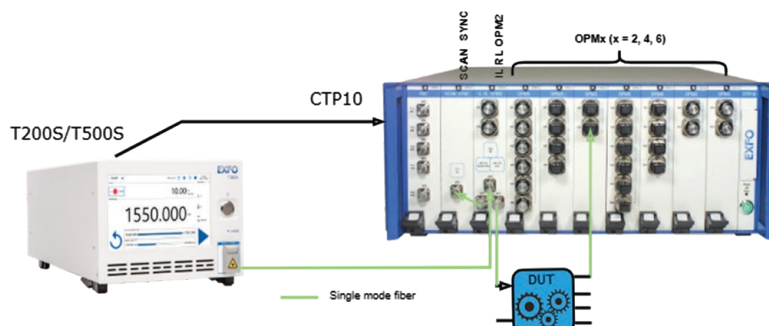
- TF_{ref} Reference measurement without DUT
- TF_{meas} TF measurement with DUT
- TF_{DUT} TF of the DUT

Reference without DUT



$$TF_{ref} = P_{ref}^{OPM} - P_{ref}^{monitoring}$$

Measurement with DUT



$$TF_{meas} = P_{meas}^{OPM} - P_{meas}^{monitoring}$$

IL DUT

The IL of the DUT can be calculated as follows:

$$TF_{DUT} = TF_{meas} - TF_{ref}$$

$$TF_{DUT} = [P_{meas}^{OPM} - P_{meas}^{monitoring}] - [P_{ref}^{OPM} - P_{ref}^{monitoring}]$$

$$TF_{DUT} = [P_{meas}^{OPM} - P_{ref}^{OPM}] - [P_{meas}^{monitoring} - P_{ref}^{monitoring}]$$

$$IL_{DUT} = -TF_{DUT}$$

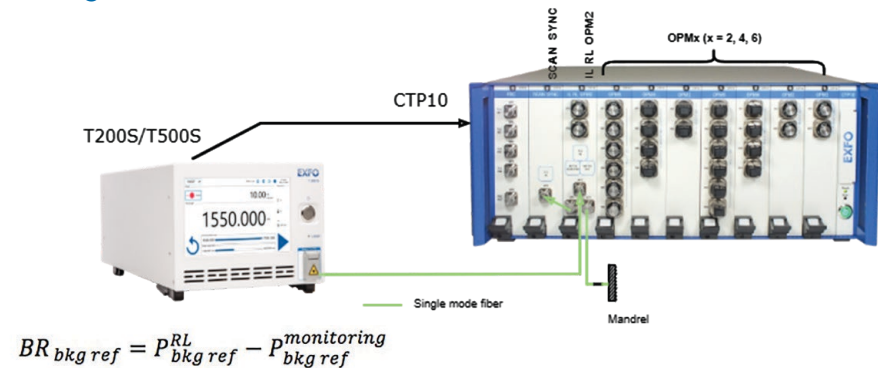
The expression of TF_{DUT} was rewritten to show that the power terms noted P can be grouped together by detector. What makes a measurement relative is the fact that the final result IL_{DUT} solely depends on the difference between two power values acquired on the same detector. Any offset in the power value returned by any of the detectors will impact all measurements identically and will therefore be cancelled out.

Return loss

Terminology:

- $BR_{bkg ref}$ Background noise reference measurement with a patchcord winded around a mandrel.
- $BR_{loss ref}$ Loss reference measurement with a component of known RL
- BR_{meas} BR measurement with DUT
- BR_{DUT} Backreflection of the DUT

Background noise reference



Loss reference

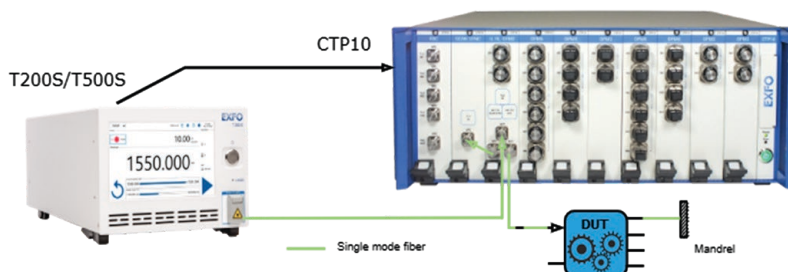


$$BR_{loss ref} = P_{loss ref}^{RL} - P_{loss ref}^{monitoring}$$

$$Shift = BR_{absolute reference} - BR_{loss ref}$$

$$Shift = BR_{absolute reference} - [P_{loss ref}^{RL} - P_{loss ref}^{monitoring}]$$

Measurement with DUT



$$BR_{meas} = P_{meas}^{RL} - P_{meas}^{monitoring}$$

RL DUT

$$BR_{DUT} = 10 \cdot \log_{10} \left[10^{\frac{BR_{meas}}{10}} - 10^{\frac{BR_{bkg ref}}{10}} \right] + Shift$$

The detailed calculation to rewrite this expression is shown in Appendix 1, the final result is given below:

$$BR_{DUT} = BR_{absolute reference} + 10 \cdot \log_{10} \left[10^{\frac{A}{10}} - 10^{\frac{B}{10}} \right]$$

With A and B defined as follows:

$$A = (P_{meas}^{RL} - P_{loss ref}^{RL}) + (P_{loss ref}^{monitoring} - P_{meas}^{monitoring})$$

$$B = (P_{bkg ref}^{RL} - P_{loss ref}^{RL}) + (P_{loss ref}^{monitoring} - P_{bkg ref}^{monitoring})$$

$$RL_{DUT} = -BR_{DUT}$$

Although this expression is more complex than the one obtained in the case of IL, we can see that the power terms can still be grouped in a way that confirms that RL_{DUT} is indeed relative when the reference measurements are performed beforehand.

The table below summarizes the cases where RL_{DUT} is relative depending on whether the background noise reference and loss reference are performed or not. It can be shown that the loss reference measurement using a component of known RL is what makes RL_{DUT} relative.

Background noise reference	Loss reference	RL_{DUT} relative?
No	No	No
Yes	No	No
No	Yes	Yes
Yes	Yes	Yes

Conclusion

This application note described what makes a measurement relative and the formalism that can be used to check whether a measurement is relative or not. Insertion loss and return loss measurement are relative measurements if the proper referencing procedure is followed:

- Insertion loss

1. Reference measurement without DUT
2. Measurement with DUT

- Return loss

1. Background noise reference measurement with mandrel wrap
2. Loss reference measurement using a component of known return loss
3. Measurement with DUT

In the case of return loss, the background noise reference does not contribute to make the result relative but rather allows to increase the dynamic range of the measurement.

Learn more

[CTP10 - Passive optical component testing platform](#)

Appendix

The following calculation details how BR_{DUT} , the backreflection of the DUT, can be rewritten in a way that shows that it is relative when both reference measurements are performed beforehand. The background noise is assumed to be sufficiently low so that its influence on the loss reference measurement can be neglected.

Terminology:

- $BR_{bkg\ ref}$ Background noise reference measurement with mandrel wrap.
- $BR_{loss\ ref}$ Loss reference measurement with a component of known RL.
- BR_{meas} BR measurement with DUT.
- BR_{DUT} Backreflection of the DUT.

$$BR_{DUT} = 10 \cdot \log_{10} \left[10^{\frac{BR_{meas}}{10}} - 10^{\frac{BR_{bkg\ ref}}{10}} \right] + Shift$$

$$BR_{DUT} = 10 \cdot \log_{10} \left[10^{\frac{P_{RL_{meas}} - P_{monitoring_{meas}}}{10}} - 10^{\frac{P_{RL_{bkg\ ref}} - P_{monitoring_{bkg\ ref}}}{10}} \right] + BR_{absolute\ reference} - [P_{RL_{loss\ ref}} - P_{monitoring_{loss\ ref}}]$$

$$10^{\frac{BR_{DUT} - BR_{absolute\ reference}}{10}} = \left[10^{\frac{P_{RL_{meas}} - P_{monitoring_{meas}}}{10}} - 10^{\frac{P_{RL_{bkg\ ref}} - P_{monitoring_{bkg\ ref}}}{10}} \right] \cdot 10^{\frac{P_{monitoring_{loss\ ref}} - P_{RL_{loss\ ref}}}{10}}$$

$$10^{\frac{BR_{DUT} - BR_{absolute\ reference}}{10}} = 10^{\frac{P_{RL_{meas}} - P_{RL_{loss\ ref}} + P_{monitoring_{loss\ ref}} - P_{monitoring_{meas}}}{10}} - 10^{\frac{P_{RL_{bkg\ ref}} - P_{RL_{loss\ ref}} + P_{monitoring_{loss\ ref}} - P_{monitoring_{bkg\ ref}}}{10}}$$

$$BR_{DUT} = BR_{absolute\ reference} + 10 \cdot \log_{10} \left[10^{\frac{A}{10}} - 10^{\frac{B}{10}} \right]$$

With A and B defined as follow:

$$A = (P_{RL_{meas}} - P_{RL_{loss\ ref}}) + (P_{monitoring_{loss\ ref}} - P_{monitoring_{meas}})$$

$$B = (P_{RL_{bkg\ ref}} - P_{RL_{loss\ ref}}) + (P_{monitoring_{loss\ ref}} - P_{monitoring_{bkg\ ref}})$$