Factors influencing the uncertainty of optical attenuator measurements

Solutions Brief

Optical attenuators, like all test and measurement equipment for device characterization, can never offer 100% accuracy; however, some attenuators are more accurate than others.

In general, the fewer errors your measurement instruments contribute to the overall error, the lower the margin required when specifying the DUT.

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Furthermore, you must obviously select instruments with the right features and specifications for your particular application. For example: an 850nm multi-mode attenuator wouldn't appear in a 1550nm single-mode setup. There are other important, but less obvious parameters to be considered when choosing your test instruments, which are discussed here.

In which applications might you use an optical attenuator?

Usually, in an application like that illustrated below, an optical attenuator is used to simulate the loss that is induced by an optical fiber.

Diagram 1 illustrates a typical attenuator setup. Which might be used in the following applications:

- Bit error rate measurements on digital transmission links, here the stimulus/response unit is a bit error rate tester (BERT).
- Analog CATV; here, the stimulus used to test the transmission link can be a set of TV channels, where the user checks the quality of the transmission at different power levels. In this case, the response unit might be the TV set.
- EDFA measurements; here the transmitter would be an EDFA (erbium doped fiber amplifier), stimulated by short optical pulses. The output pulse characteristics will be measured by a fast O/E converter (in this application the attenuator is used to adapt the EDFA's output to a level that is appropriate for the O/E converter). Here, the stimulating optical pulses will be adjusted to appropriate power levels by using an additional attenuator.
- In other applications the receiving part of the test setup might be an optical spectrum analyzer (OSA) or a wavemeter.

Often a fixed part of the attenuator's output is coupled out so that it can be monitored by an optical power meter e.g. to observe power fluctuations of the source or calibrate for an unknown transmitter wavelength.

Factors influencing the uncertainty of attenuator measurements

There is one common requirement for all the above applications: the optical power must be attenuated precisely without interfering with the rest of the system. When choosing an optical attenuator, the specifications for the following will be important considerations:

- Accuracy (linearity)
- Repeatability
- Return loss
- Polarization dependent loss
- Resistance to applied power (important in high power applications)

Another factor to be considered is the attenuator's ability to change from one attenuation level to the other continuously, without overshoots, undershoots or glitches (see repeatability).

The rest of this paper explains the significance of these parameters and, particular, their relevance to the Agilent 8156A optical attenuator.

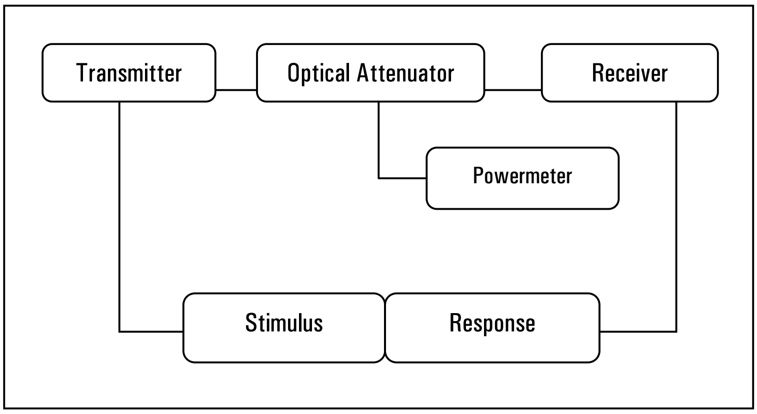

Diagram 1 Typical setup for optical attenuator applications

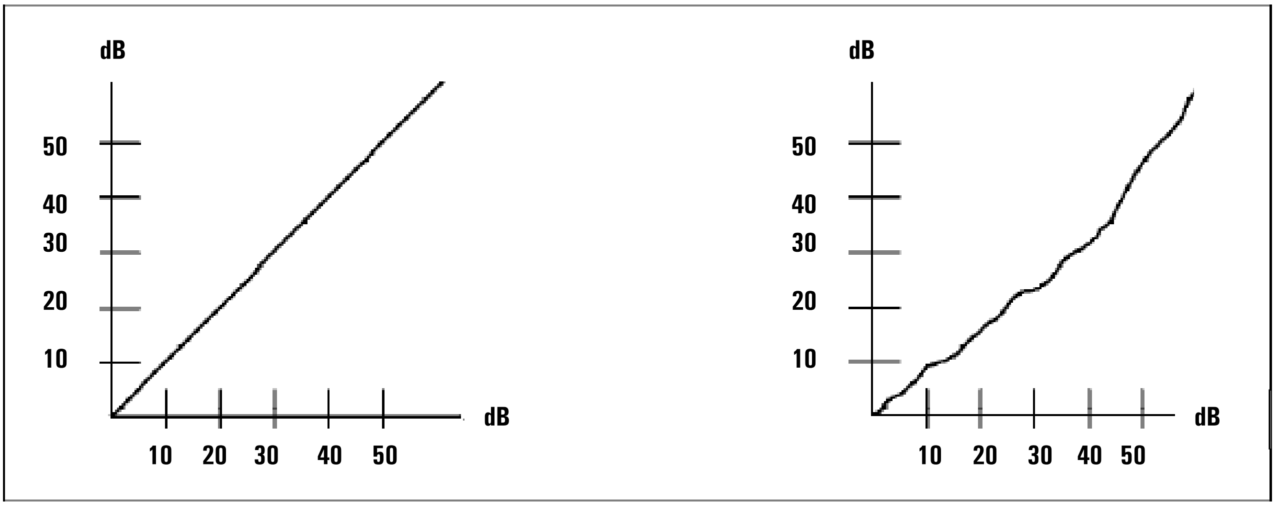

Diagram 2: Ideal and real traces of measured of vs. programmed attenuation

Accuracy, linearity

When you increase your attenuation by 20 dB you expect to get an attenuation increase of 20.000dB. In reality, however, this is unlikely. Instead, you will probably see an attenuation increase of e.g. 19.997 dB or 20.005 dB. The deviation between the programmed attenuation and the attenuation actually measured is referred to as linearity or accuracy. The deviation between programmed and measured attenuation vs. programmed attenuation is referred to as accuracy. (Diagram 2)

To achieve the accuracy and linearity shown in Diagram 3, the Agilent 8156A is calibrated at two wavelengths, around 1310 nm and 1550 nm . Its built-in calibration software corrects for the wavelength dependence of the filter.

If you want to improve the accuracy of your measurement when using lasers with several and maybe unsymmetrical modes or an unknown wavelength, you can easily optimize the attenuator's performance as follows:

First, set the attenuator to its 0 dB position, program it to the approximate wavelength of your source. Connect a power meter (e.g. Agilent 8153A + Agilent 81532A) to its output, program its wavelength to your best guess of the source's wavelength (with the wavelength dependence of InGaAs detectors, the exact wavelength is not important) and set it do dB-mode. Pressing Disp->Ref zeroes the display.

When you now change the attenuation to e.g. 60 dB, the power meter's display might show up e.g. 59.89 dB. Now, you modify the attenuator's wavelength until the power meter shows 60 dB. This procedure ensures that the accuracy of the attenuator is optimized for your source.

Repeatability

The term repeatability mainly describes the quality of the positioning system that moves the attenuating filter to its programmed position (=attenuation). Consider the BERT application, where you are trying to find the power level at which the bit error rate exceeds some critical threshold.

The fastest way to determine this value is by means of successive approximation. You try to find an approximate attenuation level, where the bit error rate (BER) is well below the acceptance level, and an attenuation level, where BER exceeds the limit.
By repeatedly halving the interval within which you measure for excessive BER, you can find that level quickly and methodically. Clearly, the positioning of

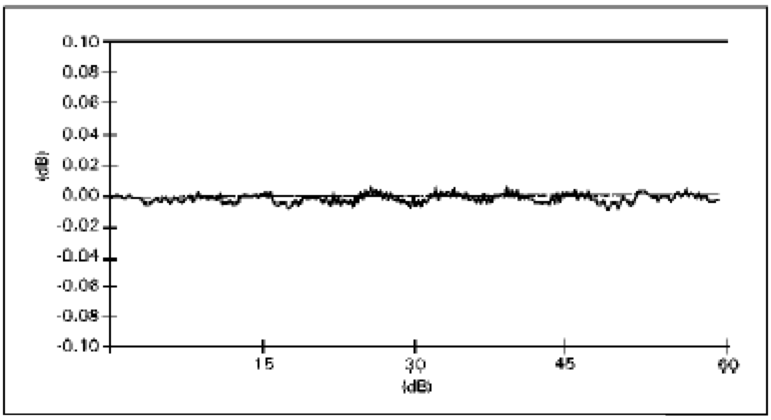

Diagram 3 Trace showing the attenuation accuracy of the Agilent 8156A

the filter back and forth around the threshold level must be fast, exact, and without over and undershoots, so as not to lose synchronization.

The Agilent 8156A typically offers an exceptional repeatability of well below 0.005 dB due to a positioning system that lets you control the filter position down to less than 0.0014. Furthermore, the attenuation can be set continuously ("glitch-free") over the whole range from 0 to 60 dB. And it can be set quickly, with a typical settling time of 200 ms.

Polarization dependent loss

As the accuracy of instruments continues to improve, one attenuator specification has also grown in importance: polarization dependence. Sensitivity to changing states of polarization can be seen by connecting a laser to an optical components (DUT) input, its output to a power meter and then twiddling the fiber.

Generally, the power will change. This is due to the polarization dependent loss of the DUT and also due to the polarization dependent sensitivity of the power meter.

If, in a setup like that shown in Diagram 1, you use an attenuator, you don't want it to show misleading results due to the changing states of polarization of the incoming optical power.

Therefore, the selection of an attenuator with low polarization dependent loss is essential for your application. An optical attenuator can comprise one of two kinds of filters: absorbing glass filters or metal film (metal coated) filters.

The disadvantage of metal coated filters is that they exhibit a strong polarization dependent loss (PDL), i.e. depending on the state of polarization of the optical power that travels through such a filter, the filter's loss varies in the order of several tenths of a dB. Furthermore, this filter's PDL causes the loss to be less than the nominal value at one position of the filter and higher than the nominal value at another filter position, causing a significant deterioration in the attenuator's linearity.

The alternative is a filter that applies absorbing glass. The very small amount of PDL that it exhibits causes only very small deviations from the nominal value. Also, this deviation remains constant at other filter positions, ensuring excellent linearity values. This superior PDL performance (Diagram 4) more than compensates for its only disadvantage compared to metal coated filters - higher wavelength dependence since this will be corrected by the attenuator's software. (see above)

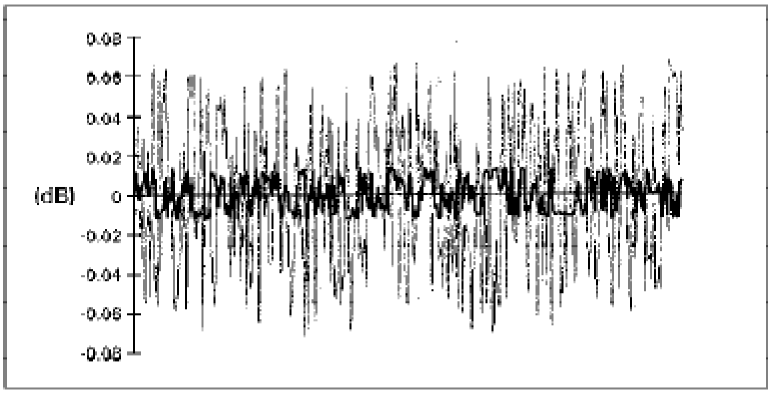

Diagram 4 Polarization dependence of absorbing glass attenuator (dark) vs. Metal coated attenuator (light)

Resistance to applied power

With the increasing use of EDFAs in telecom applications, a requirement has emerged for much higher power levels than in the past This, in turn, required special design considerations for equipment to be able to withstand these power levels.

In the worst case, the high power might destroy the equipment you're using, if it was not properly selected for high power applications. While some attenuators may claim to offer high power measurements, not all are able to do so in practice. To prove the accuracy of the Agilent 8156A in high power applications, we applied CW-power in the order of 23 dBm for some hours and then measured the accuracy again. The above graphs show the results (Diagram 5a and 5b)

Conclusion

It is clear from this paper that a number of specifications influence the accuracy of test instruments. The Agilent 8156A optical attenuator is the ideal instrument for all applications requiring precise optical power attenuation. Its range of options means you can choose the one that is most appropriate for your application in terms of performance parameters such as return loss, accuracy, monitoring capabilities and price.

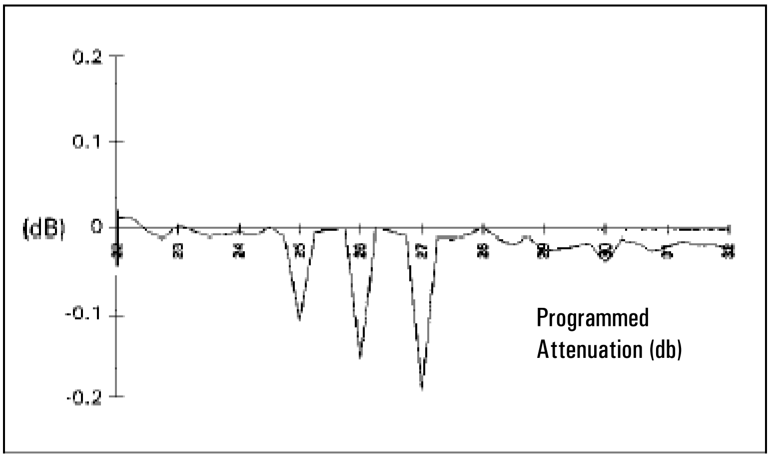

Diagram 5a An attenuator that does not withstand 23 dBm

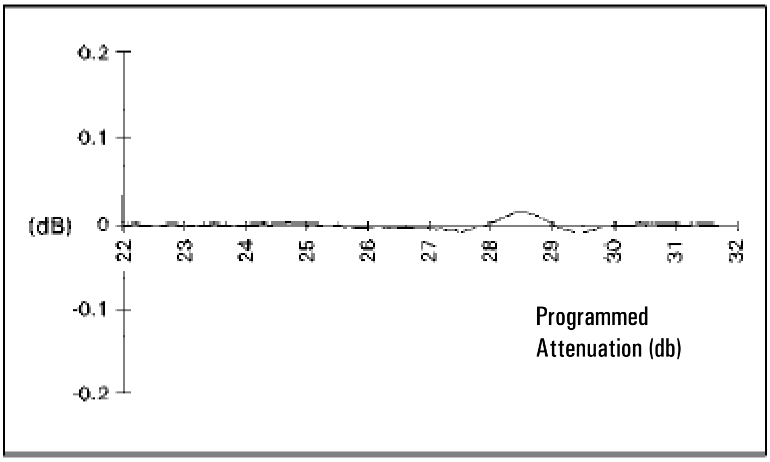

Diagram 5b The accuracy of the Agilent 8156A after applying 23 dBm

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