CALIBRATION OF OPTICAL POWER METERS

By, Marie-Hélène Côté, Senior Product Manager

Finding ways to optimize the performance of test equipment is one of the primary issues for managers, yet maintaining a large inventory of test and measurement equipment requires a systematic and efficient approach. This makes regular calibration of test and measurement equipment one of the most important parts of quality assurance and maintenance programs—ensuring high yield operation and customer satisfaction. EXFO can help save both time and costs with an automated calibration test system that is designed for the verification of power meters, attenuators, sources and optical time-domain reflectometers (OTDRs).

This application note demystifies how EXFO's IQS-12002 Optical Calibration System can guide you through the calibration of power meters, covering issues such as traceability and technical characteristics of detectors, while explaining the procedure in detail.

Traceability

According to national and international standards, the calibration of instruments such as optical power meters consists of a set of operations that establish, under specified conditions, the relationship between the values indicated by the measuring instrument and the corresponding known values of a measurement. The calibration is performed by comparing the readings of a device under test (DUT) to those of a working standard with an accuracy that is much better. The working standard is calibrated against a reference standard that in turn, is calibrated against a national standard at reference conditions. The path between a company working standard and the national standard of a known laboratory, such as the NIST, is presented in the example of a calibration chain in Figure 1. Other laboratories such as NRC-CNRC in Canada, PTB in Germany and NPL in the UK are recognized internationally.

National metrology institutes that are signatories to the Mutual Recognition Arrangement of the International Committee of Weights and Measures are recognized all over the world in the participating countries. The signatories recognize the degree of equivalence of national measurement standards and the validity of calibration and measurement certificates issued by participating institutes. The list of the signatories is available at: http://www.bipm.fr/pdf/signatories.pdf.

When using a commercial power meter, it is important to ensure that uncertainty associated with the instrument lies within an acceptable range. This value is usually given by the manufacturer of the instrument (identified as uncertainty or accuracy in the specification sheet). In order to guarantee this specification, manufacturers of test equipment rely on the use of reference and working standards. Commercial power meters are calibrated using working standards that are periodically verified against reference standards, which are regularly calibrated by a national metrology institute (NIST in the case of EXFO).This traceability chain ensures consistent quality of commercial instrument.

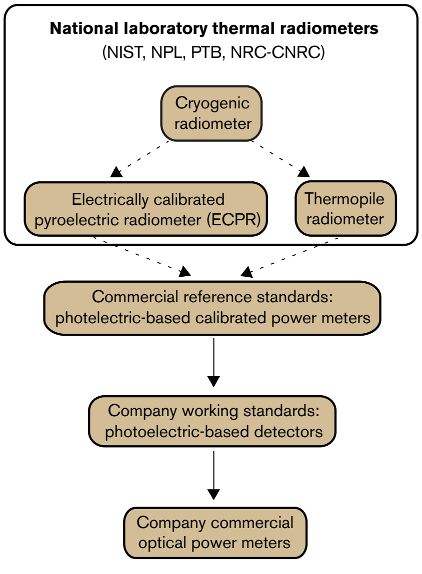


Figure 1. Typical calibration chain

Responsivity Calibration

The responsivity of power meters, based on photoelectric detectors, is measured in ampere per watt of light received by the detector—responsivity is wavelength dependent. The responsivity calibration consists in reproducing the whole of the responsivity curve of the DUT, or part of this curve, by comparing the device under test (DUT) with a reference power meter. Figure 2 illustrates the responsivity of the main types of photoelectric detectors.

Both power meters are compared sequentially and tuned to the source wavelength using a singlemode fiber; this method is sensitive to the power stability of the source. Broadband white light sources are the only sources that can be used to calibrate photoelectric detectors across their full wavelength regions. The ideal and most economic setup uses different wavelengths from different sources, such as semi-conductor laser sources. The most important wavelengths in the telecommunications industry are 1310 nm and 1550 nm, and an attenuator is placed between the light source and the power meter to set the power to the appropriate level. The standard procedure (IEC-61315) recommends -10 dBm as the calibration reference power.

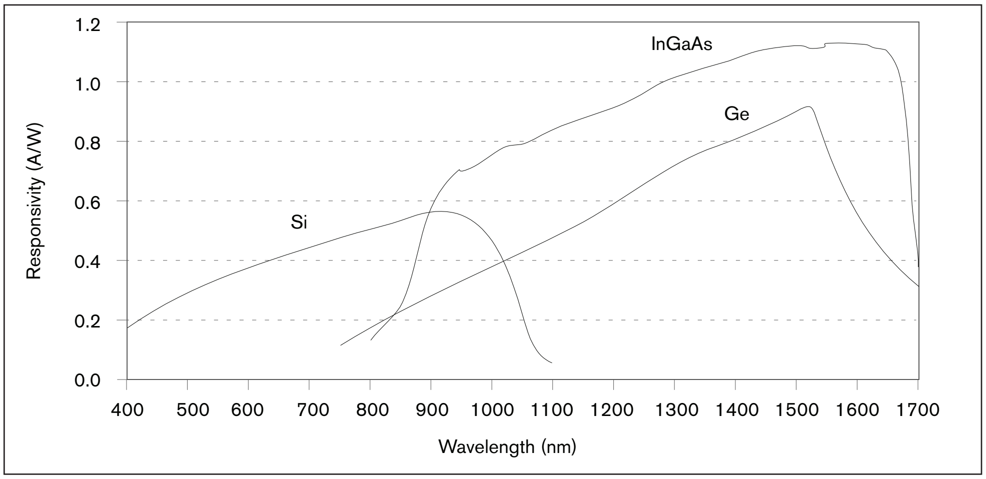


Figure 2. Responsivity of photoelectric detectors

The deviation between the readings of the reference power meter (P_{ref}) and the readings of the DUT (P_{DUT}) leads to a calibration factor (CF). The reference conditions of the calibration are discussed in the following:

- The very narrow, singlemode linewidth of standard distributed feedback (DFB) lasers corresponds to a long coherence length that renders the detected intensity extremely sensitive to small, residual reflections along the transmission path–producing Fabry-Perot type interference. But if their spectrum is broadened to have a coherence length of a few meters or less, such parasitic etalon effects are greatly suppressed and the source becomes well-suited for calibration, having extremely steady power and a very stable, well-defined precise wavelength, which can accurately be measured
- Singlemode fiber is preferred because this is the fiber used in telecommunications
- Movement of the fiber should be kept to a minimum to minimize polarization effects
- Environmental conditions should be controlled: typically 23°C and 50% of relative humidity
- All connectors and connector adapters must be inspected and cleaned if needed
- Allow a warm-up time of at least 15 minutes or as recommended by the manufacturer of the DUT and the reference power meter
- A null measurement is required before starting the measurement on both the DUT and reference power meter

When evaluating uncertainties of a calibration, all the above and following parameters should be taken into account:

1. Source power stability
2. Fiber stability
3. Error due to the combination of the source wavelength uncertainty and the spectral sensitivity of the power meters around each wavelength calibration point
4. Possible errors if the source bandwidth is too large (if a LED source is used)
5. Type of fiber and connector used if different from the calibration of the reference standard
6. Responsivity temperature dependence of the detector based on temperature uncertainty
7. Linearity at the set power level if different from the reference power level of the reference standard
8. Dependence on state of polarization (singlemode fibers)
9. Aging of the power meter
10. Uncertainty of the reference power meter at reference conditions
11. Any other dependence

EXFO Calibration System

The IQS-12002 is a turnkey system offering a step-by-step optical calibration procedure with integrated software; this system is a great alternative to customers who use reference power meters and manual procedures that require time and are subject to user mistakes. Some large companies prefer to sub-contract the calibration of their instruments to have peace of mind, but at a very high price. Why worry and subcontract the verification of an instrument when one can do it in-house at a reasonable cost, save a lot of time and get peace of mind? A regular verification of test instruments enables to check if the instrument still falls within its specs and ensures that only the equipment that need tuning will be returned to the manufacturer for adjustment. Customers may also want to verify the specs of other instruments, such as light sources, attenuators and OTDRs.

The IQS-12002 Optical Calibration System offers a series of tests managed by high level software:

1. Absolute power calibration and linearity of optical power meters
2. Light source output power stability
3. Variable attenuator linearity, repeatability, insertion loss and optical return loss

A manual procedure to verify the attenuation and distance range of OTDRs is also available.

Based on the building block architecture of the IQS-500 Intelligent Test System, the IQS-12002 uses the IQS-1500 Calibration Power Meter as a reference standard. EXFO recommends that the IQS-1500 be calibrated at the NIST with an accuracy of ±0.9% and a linearity of ±0.01 dB. Based on a 5 mm diameter cooled germanium detector, the IQS-1500 is stable in temperature and presents uniform response on its active area and is less sensitive to polarization when compared to an InGaAs detector. The large size of the detector ensures full collection of light, making this power meter suitable for telecommunications applications and therefore, the best calibration power meter available on the market.

The IQS-1500 is supplied with the fiber-optic adapter and reference test jumper used for its own calibration, so that any commercial power meter, whether handheld or benchtop, can be tested in conditions as close as possible to the calibration reference conditions. The DUT power meter is compared to this reference power meter in the setup, including a DFB laser source at 1310 nm and/or 1550 nm and an attenuator. The IQS-12002 calibration software controls the measurements from start to finish–according to user-selected parameters, eliminating the possibility of data entry and reporting error, which avoides costly procedural mistakes. Time-saving features such as pass/fail testing and automatic prompting for the next device to test make the IQS-12002 considerably efficient. In addition, complete reports with data tables and graphs can be printed in summary or detailed formats, and all the information on each DUT is saved in a database. Most importantly, the software calculates the calibration factor and the total uncertainty of the DUT.

If the DUT has this feature, the calibration factor is entered either as an offset at each wavelength and the configuration is saved, or if the User-Cal feature is available, the calibration factor can be entered in the non-volatile memory of the power meter under test.

Recommended Reference Conditions	
Temperature	23 ±1°C
Relative humidity	50 ±10%
Fiber	Singlemode
Reference power	FC/UPC
Wavelengths	100 ±1°µW
Wavelengths uncertainty	1310 and 1550 nm
Spectral width of the source	±1 nm ≤1 nm and ≥0.001 nm

Table 1. Recommended reference conditions

Uncertainties Evaluation

There is always a degree of uncertainty associated with the measured calibration factor of a DUT, which is determined by performing an uncertainty analysis.

Two types of uncertainty are encountered during the calibration process: systematic and random. Systematic uncertainties are errors that are an intrinsic and constant part of the process and can be quantified or estimated from a simple measurement. Random uncertainties, on the other hand, are errors that vary from one measurement to the other and can only be estimated from statistical measurements. Random uncertainties can be minimized by averaging many measurements.

To establish total uncertainty, the uncertainty components are divided into the following:

- Random uncertainties (statistically determined from a series of measurements)
- IQS-1500 uncertainty
- Systematic uncertainties (determined by measurements and scientific judgment)

If all the mandatory uncertainties are not entered, the software will not be able to compute a total uncertainty because it could be underestimated. The IQS-1500 uncertainty is a mandatory random uncertainty.

The remaining uncertainties that are not mentioned in this article are optional, but to obtain the best results possible, all uncertainties should be considered.

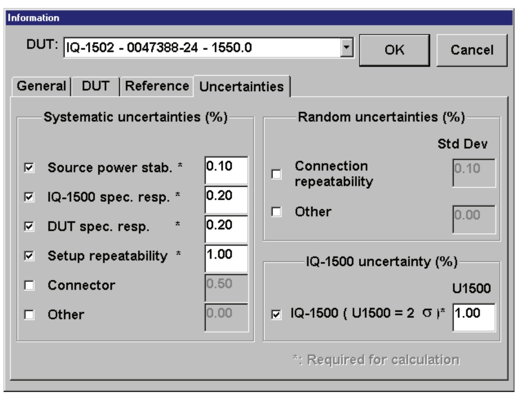


Figure 3. User-selectable parameters are used to calculate the uncertainties

Systematic Uncertainties

The systematic uncertainty components are also assumed to be independent and have rectangular distributions. The following sources of information may be helpful in evaluating these systematic uncertainties:

- Previous measurement data
- Manufacturer specifications
- Data provided in calibration and other reports

The mandatory systematic uncertainties are:

- Source power stability
- IQS-1500 spectral response effect
- DUT spectral response effect
- Setup repeatability

The following paragraphs describe the systematic uncertainties that have to be estimated. All the entries must be the half width, U_{si}, of a rectangular distribution from $-U_{si}$ to $+U_{si}$, in percent.

The source power stability is very important since the calibration is sequential (i.e., measurements are taken first on the IQS-1500 and then on the DUT). This first source of error can be evaluated by measuring the variation of the source power on one power meter over the time of calibration at one wavelength, which is approximately one minute.

The IQS-1500 spectral response slope, in %/nm, around the wavelength of the source influences calibration because of the uncertainty associated with the source wavelength. If not already known, the slope can be calculated using the following procedure:

1. With a stable light illuminating the detector, set the IQS-1500 to the wavelength of the source, for example 1550.0 nm, and record the displayed power, for instance 1.000 mW.

2. Adjust the set wavelength of the IQS-1500 by the uncertainty of the wavelength of the source, for example if ±0.5 nm; set 1550.5 nm.

3. Record the second displayed power, for example 1.005 mW.

4. Calculate the slope. In this case, the variation is:

Equation 1:

$$\frac{(1.005\text{ mW} - 1.000\text{ mW})}{(1.005\text{ mW} \times 0.5\text{ nm})} = \frac{0.5\%}{0.5\text{ nm}} = 1\%\text{ /nm}$$

The error is then 0.5% for a 0.5 nm uncertainty or 1% per nm.

The DUT spectral response slope around the wavelength of the source has an effect similar to that of the IQS-1500. It can also be evaluated the same way if the spectral resolution of the DUT is also 0.1 nm. If not, an estimate can be obtained by setting the second wavelength as close as possible to 1550 nm (e.g., 1540 nm). The evaluation will then be less precise and judgment is important to ensure a good estimation.

If a launch test jumper different than the one used for the calibration of the IQS-1500 is used during the verification procedure, a large error can occur due to the mating characteristics of the connector. The IQS-1500 comes with the standard reference test jumper used for its calibration.

The setup repeatability also has to be measured and recorded. Movements of the fibers are mainly responsible for this error source. If the fiber has to be twisted between the IQS-1500 and DUT, this effect needs to be measured.

In addition, any other systematic error may be entered and included in the total uncertainty calculation.

Random Uncertainties

The random uncertainties are assumed to be independent but are normally distributed; therefore, they can be estimated by performing a series of measurements and calculating a standard deviation. For instance, even though the same fiber is used, the repeatability of the connection on both power meters must be measured and taken into account.

IQS-1500 Uncertainty

It is important to indicate the uncertainty of the calibration of the IQS-1500 found in the Report of Calibration provided with the IQS-1500 Calibration Power Meter. The uncertainty must be established at a 95% (2 σ) confidence level; if not, correct the value to 2 σ confidence level. For instance, if the confidence level is specified at 68% (1 σ), then multiply the uncertainty by two.

Calibration Factor Calculation

The calibration factor (CF) is calculated using Equation 2.

Equation 2:

$$CF = \frac{P_{1500}}{P_{DUT}}$$

where P_{1500} = IQS-1500 measured power in watts and

P_{DUT} = DUT measured power in watts

Standard Deviation of the Calibration Factor

The standard deviation (SD) of the calibration factor for the DUT is automatically calculated by the software, as described in Equation 3. For reliability, the process should be repeated the largest number of times (N).

Equation 3:

$$SD = \sqrt{\frac{\sum_i (CF_i^2) - \frac{1}{N}\left(\sum_i CF_i\right)^2}{N-1}}$$

Total Uncertainty

The total uncertainty (when the calibration factor is applied) is calculated by adding, using the root of the sum of the squares, the systematic, random, and IQS-1500 uncertainties and multiplying the result by two to obtain a confidence level of 95%, as shown in Equation 4.

Equation 4:

$$U_t = 2 \times \sqrt{\sum_i \left(\frac{U_{si}^2}{3}\right) + \sum_i \left(\frac{U_{ri}^2}{N}\right) + \left(\frac{U_{1500}}{2}\right)^2}$$

where U_t = total uncertainty, U_{si} = systematic uncertainties,

U_{ri} = random uncertainties, and

U_{1500} = IQS-1500 calibration uncertainty and

N = the number of measurements

Optical Linearity

The absolute power calibration is performed at one power level only. How accurate the power measurements are at power levels other than the calibration power is determined by the linearity of the power meter.

The linearity of the power meter is directly related to the accuracy of relative power measurements such as loss measurements (gain, isolation, crosstalk, insertion loss, optical return loss and polarized dependent loss). Ideally, the readings of a power meter should be accurate at each power level; a linearity measurement can reveal whether this is the case.

By definition, the non-linearity (NL) at a given power level is the difference between the responsivity at this power level (R_p) and the responsivity at the reference power (R_{ref}: the power level at the absolute power) divided by the responsivity at the reference power level. This non-linearity should remain as small as possible at other power levels.

Equation 5

$$NL = \frac{R_p - R_{ref}}{R_{ref}}$$

By definition, the non-linearity is equal to zero at the reference power level.

Measurement Method

The highest accuracy method to measure linearity is the addition method, also referred to as the superposition method. This method also has the advantage of being independent from any reference power meter, and it does no rely on the linearity or accuracy of the attenuators present in the setup. Using a coupler to split the power in two and then adding a shutter on both legs (paths) before recombining the power using a second coupler connected to the power meter under test, plus measuring the power coming from each leg (P_A and P_B) and also from both legs reunited (P_{total}) is required by this method. The deviation of P_{total} from $P_A + P_B$ is the local linearity (LL). Adding the local linearities (they can be both positive or negative) and referencing to the reference power will give the total linearity error (L_{global}).

By adding an attenuator between the source and the first splitter, the total power is then attenuated by a factor 2 (3 dB) with respect to the previous step. This process is repeated throughout the desired range in order to characterize local linearities over a large power range.

However, before performing the linearity test, both legs have to be balanced. Balancing the linearity setup is essential to guarantee that the power used for testing is equal on both legs. It is the basis of the addition method used for linearity measurement. This method is independent from the linearity of the attenuators in the setup and does not rely on the use of a reference power meter.

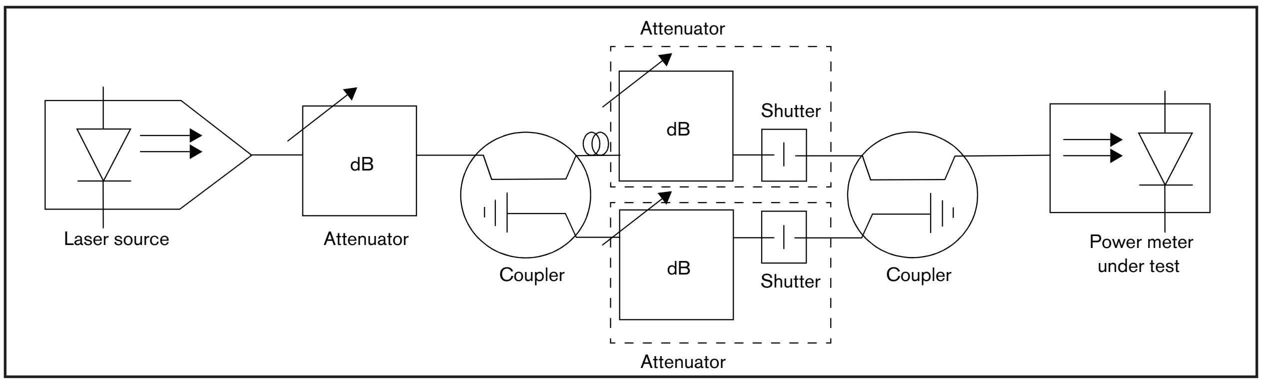


Figure 4. Typical setup for measuring the optical linearity of power meters using the superposition method

This is the best approach to optimize power balancing. DFB lasers are recommended because they are stable and optically isolated to reduce sensitivity to reflections. Their linewidth must be broadened to minimize coherence-related problems during the calibration procedure. The two paths of the setup should have different lengths to avoid Mach-Zehnder-type interference fluctuations and unused branches of couplers must be terminated. The drawback of this method is its higher insertion loss (typically 7 dB). For higher power measurements, an optional optical amplifier (EDFA for the 1.55 µm band) can be inserted between the source and the first attenuator.

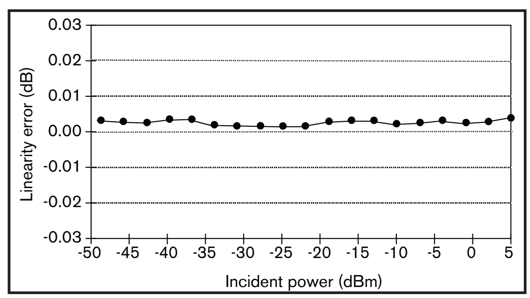


Figure 5. Linearity results of a Ge detector

Results of measurements using the IQS-12002 are presented in Figure 5 and Figure 6. In Figure 5, a 5 mm germanium calibration power meter (used as a reference standard) offers a linearity value within ±0.005 dB at 1550 nm over the range -50 dBm to +5 dBm.

Figure 6 shows a result in the same conditions for 1 mm InGaAs detector. A good linearity, within ±0.015 dB from -50 dBm, up to +2 dBm, followed by a very fast saturation between +2 dBm and +5 dBm was observed.

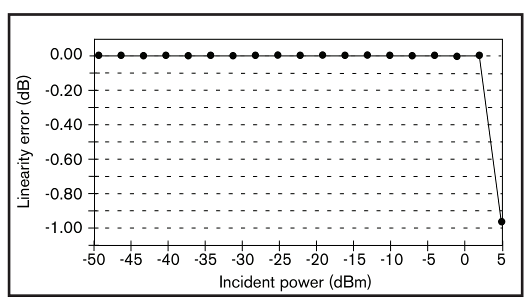
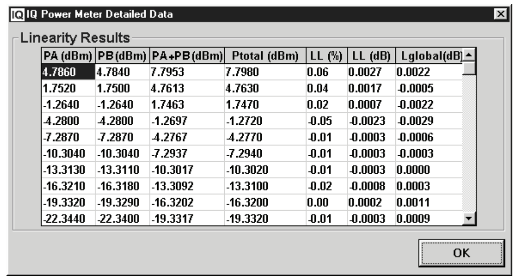


Figure 6. Linearity results of an InGaAs detector

The IQS-12002 Optical Calibration System linearity test determines the linearity error with an uncertainty better than ±0.01 dB.

Detailed Data with the IQS-12002 Optical Calibration System

In the results table, the first two columns contain the measured power in dBm for each leg: P_A and P_B. The third column is the calculated total power ($P_A + P_B$) in dBm. The fourth column shows the measured total power (P_{total}) in dBm in both legs. The next two columns contain the calculated local linearity expressed in % and dB. The local linearity is calculated as the difference between the total power measured and calculated: $LL = P_{total} - (P_A + P_B)$. The last column is the calculated global linearity obtained by adding the local linearities from the reference power. The resulting linearity is the highest value of the last column.


IQ Power Meter Detailed Data

Linearity Results

PA (dBm)	PB(dBm)	PA+PB(dBm)	Ptotal (dBm)	LL (%)	LL (dB)	Lglobal(dB)
4.7860	4.7840	7.7953	7.7980	0.06	0.0027	0.0022
1.7520	1.7500	4.7613	4.7630	0.04	0.0017	-0.0005
-1.2640	-1.2640	1.7463	1.7470	0.02	0.0007	-0.0022
-4.2800	-4.2800	-1.2697	-1.2720	-0.05	-0.0023	-0.0029
-7.2870	-7.2870	-4.2767	-4.2770	-0.01	-0.0003	-0.0006
-10.3040	-10.3040	-7.2937	-7.2940	-0.01	-0.0003	-0.0003
-13.3130	-13.3110	-10.3017	-10.3020	-0.01	-0.0003	0.0000
-16.3210	-16.3180	-13.3092	-13.3100	-0.02	-0.0008	0.0003
-19.3320	-19.3290	-16.3202	-16.3200	0.00	0.0002	0.0011
-22.3440	-22.3400	-19.3317	-19.3320	-0.01	-0.0003	0.0009

OK

Figure 7. Linearity results table

Advantages of the IQS-12002 Integrated Solution

The IQS-12002 Optical Calibration System is efficient and user-friendly. The main features of the IQS-12002 Calibration System include:

- Step-by-step operating instructions in both graphic and text format
- Detailed information about each DUT saved in a database
- Detailed reports with data tables and graphs that can be printed in summary or detailed formats
- PC-based Windows 98 environment.

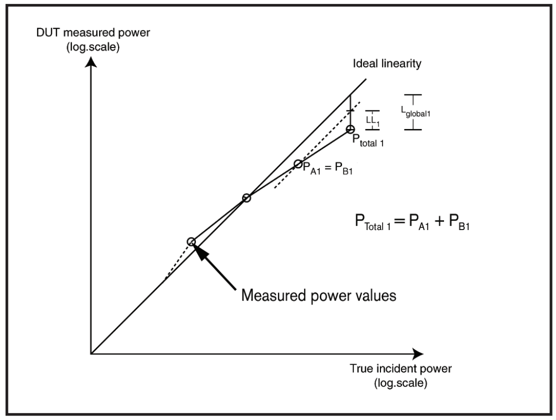


Figure 8. Linearity measurement method

Conclusion

The absolute power calibration of fiber-optic power meters using turnkey integrated software enables the user to verify the absolute calibration based on the IEC-61315 standard to determine and then input a multiplicative correction factor to the high level software to correct the displayed value at a certain wavelength. This is a useful procedure for customers having many power meters in their laboratory or the field. Consequently, only a fraction of the instruments will be returned to the factory for complete recalibration. Note that linearity is the key issue in relative power measurements such as insertion loss. Linearity is also an important parameter to consider when performing calibration of power meters and the superposition method used in the IQS-12002 system greatly eases the verification process.

EXFO Corporate Headquarters > 400 Godin Avenue, Quebec City (Quebec) G1M 2K2 CANADA | Tel.: 1 418 683-0211 | Fax: 1 418 683-2170 | info@EXFO.com

Toll-free: 1 800 663-3936 (USA and Canada) | **www.EXFO.com**

EXFO America	3701 Plano Parkway, Suite 160	Plano, TX 75075 USA	Tel.: 1 800 663-3936	Fax: 1 972 836-0164
EXFO Europe	Omega Enterprise Park, Electron Way	Chandlers Ford, Hampshire S053 4SE ENGLAND	Tel.: +44 2380 246810	Fax: +44 2380 246801
EXFO Asia	151 Chin Swee Road, #03-29 Manhattan House	SINGAPORE 169876	Tel.: +65 6333 8241	Fax: +65 6333 8242
EXFO China	No. 88 Fuhua, First Road, Central Tower, Room 801 Futian District	Shenzhen 518048 P. R. CHINA	Tel.: +86 (755) 8203 2300	Fax: +86 (755) 8203 2306
	Beijing New Century Hotel Office Tower, Room 1754-1755 No. 6 Southern Capital Gym Road	Beijing 100044 P. R. CHINA	Tel.: +86 (10) 6849 2738	Fax: +86 (10) 6849 2662

© 2008 EXFO Electro-Optical Engineering Inc. All rights reserved.
Printed in Canada 08/02

EXPERTISE REACHING OUT