017

POWER METER CALIBRATION AT EXFO

TECHNICAL NOTE

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Introduction

When it comes to calibration, it is not enough to state that an instrument complies with published specifications; it is necessary to be ready to prove it and to have a state-of-the-art system in place to monitor and preserve the quality of all calibrations.

In 1998, EXFO decided to adopt the necessary measures to base in-house power meter calibration on the latest applicable international standards, including those established by the **International Organization for Standardization** (ISO) and the **International Electrotechnical Commission** (IEC). In order to achieve this goal, a dedicated team, consisting of both metrology and software development specialists, was created. The team's mandate was to satisfy the following objectives:

1. Improve performance
2. Ensure compliance with IEC 61315
3. Produce calibration certificates that comply with ISO/IEC 17025
4. Make a complete uncertainty evaluation based on international standards
5. Build a dedicated software and database architecture

The new system was successfully implemented and, immediately, positive results were seen: all of the objectives had been met.

Improved Performance

In addition to being fully qualified and automated, EXFO's in-house power meter calibration system (EPMCS) offers the following advantages:

- Quicker calibration time
- Minimization of uncertainties: system components were chosen and qualified before final selection
- Increased reliability: thanks to the tested ruggedness of all components and to the performance of the control software

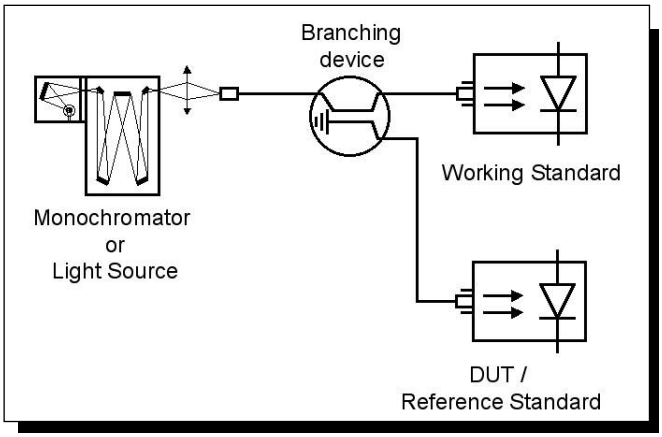

Figure 1. Optical diagram of the EPMCS

Compliance with IEC 61315

The IEC has standardized power meter calibration in IEC 61315 Calibration of fiber-optic power meters. During the development stage of the EPMCS, special care was taken to ensure compliance with the most recent version of this standard.

Consequently, a full uncertainty evaluation was carried out to determine the contribution of all relevant factors. As a result, EXFO can definitively state the calibration uncertainty and relate it directly to the guaranteed specifications at reference conditions.

EXFO's power meters are calibrated using working standards that are periodically verified against reference standards, which are regularly calibrated by NIST. These reference standards are high-quality, temperature-controlled power meters; their detectors have excellent uniformity; interference effects are minimized and their linearity is better than ± 0.01 dB over the full range. Therefore, traceability of the power meter under test to EXFO's NIST-calibrated reference standard is ensured.

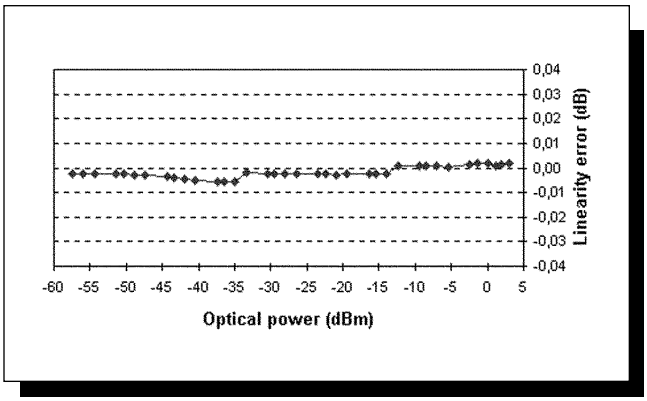

Figure 2. Linearity of an EXFO reference standard power meter at 1310 nm (measured by NIST)

Calibration Certificates that Comply with ISO/IEC 17025

Knowing customers' ever-growing concern for quality, EXFO makes every effort to ensure the compliance of calibration certificates to applicable standards. In addition to complying with the IEC 61315 standard, EXFO follows all recommendations on the calibration procedures and certificates given in ISO/IEC 17025 *General requirements for the competence of testing and calibration laboratories*.

Complete Uncertainty Evaluation

The latest international standards require that calibration uncertainties be evaluated and taken into account when a declaration of conformity is given for a specification. Our uncertainties evaluations are carried out in accordance with the guidelines stated in the *Guide to the Expression of Uncertainty in Measurement* by ISO, IEC, BIPM (**Bureau International des Poids et Mesures**) and other international organizations.

In order to ensure coherence, EXFO makes every effort to establish correspondence between calibration uncertainties, guaranteed specifications, allowed deviation between the unit and the standard, as well as the conformance assessment of the power meter's status upon reception of the unit:

a. Calibration uncertainties are expressed in the certificate. It states the combined uncertainties of the following factors:

   i. Reference standard calibration uncertainty

   ii. Dependence of the reference standard on measurement conditions

   iii. Dependence of the tested meter on measurement conditions

   iv. Other uncertainties due to the setup and measurement method

   In order to determine the contribution of these parameters, the dependence of the detector's response at each point is evaluated for the source's wavelength uncertainty, light output stability, light output bandwidth, temperature uncertainty, connector-adapter combination, fiber type, repeatability of the measurement, power meter linearity and other factors.

b. Guaranteed specifications are EXFO's published specifications for the unit (may vary depending on wavelength). Every unit that is calibrated at EXFO and returned to the customer is **guaranteed to comply with published specifications** for all parameters that are verified in the calibration process. In fact, the calibration process itself foresees the possibility of making all the necessary adjustments to ensure compliance, and written proof is given in the "As left" section of the calibration certificate when the **Within specifications** box is checked.

EXFO

400 Godin Avenue
Vanier QC G1M 2K2
Canada

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CALIBRATION CERTIFICATE

Customer:		**Address:**			
Description:	Fiber-optic power meter				
Serial no.:	233147	**Model no.:**	IQS-1643 channel 4		
Calibration location:	400 Godin Avenue, Vanier QC G1M 2K2, Canada			**Calibration date:**	2004-07-26

As found					
[ ] Initial calibration	[ ] Within specifications(i)	[X] Within specifications*(ii)	[ ] Outside specifications*(iii)	[ ] Outside specifications(iv)	[ ] Not functional
		See legend on results page for details			
Comments:					

Action taken		
[ ] No adjustment was made	[X] Adjustments were made	[ ] Repair was performed

As left	
[X] Within specifications	[ ] Outside specifications

Calibration conditions	
Temperature	23 °C ± 1 °C
Relative humidity	50 % ± 10 % N.C.
Fiber type	62.5/125 um, N.A. = 0.27, fully excited
Connector	FC/PC
Connector adapter used	FOA-222
Source	≤ 10 nm (FWHM), unpolarized
Reference power	around -35 dBm, depending on wavelength

Standards used to establish traceability				
Description	Serial number	NIST no.	Calibration date	Calibration validity
IQ-1502 - working standard	104078-31	N/A	2004-07-23	1 month
IQ-1500, Ge - reference standard	115304-34	814380	2004-06-01	12 months

Remarks:

Detectors are always cleaned before calibration.
EXFO certifies that the unit has been calibrated using standards traceable to the National Institute of Standards and Technology.
All uncertainties are reported with a level of confidence of 95 %. Calibration is based on the ISO/IEC 17025 and IEC 61315 standards.
The certificate shall not be reproduced, except in full, without the written approval of EXFO.

Summary at calibration conditions			
Wavelength range (nm)	Calibration uncertainty (%)	Specification at calibrated wavelengths (%)	Conformance limit (%)
800 to 1000	± 4.0	± 6.0	± 2.0
1000 to 1640	± 4.0	± 5.0	± 1.0
1640 to 1700	± 8.0	± 11.0	± 3.0

2005-02-22

Eric Dugal
Calibration operator

Date

Figure 3. Calibration Certificate (page 1)

EXFO

Fiber-optic power meter
Model no: IQS-1643 channel 4
Serial no.: 233147
Calibration date: 2004-07-26

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Power meter calibration results

Procedure: ILOG-00062 / IREP-00058

	As found		As left			As found		As left	
Wavelength (nm)	Deviation (%)	*	Deviation (%)	*	Wavelength (nm)	Deviation (%)	*	Deviation (%)	*
800.0	-0.61	i	-0.16	i	1260.0	-0.63	i	0.01	i
810.0	-0.66	i	-0.11	i	1270.0	-0.67	i	0.07	i
820.0	-0.78	i	0.08	i	1280.0	-0.64	i	0.04	i
830.0	-0.71	i	-0.12	i	1290.0	-0.64	i	-0.01	i
840.0	-0.59	i	-0.04	i	1300.0	-0.72	i	0.03	i
850.0	-0.59	i	-0.14	i	1310.0	-0.82	i	-0.01	i
860.0	-0.82	i	-0.05	i	1320.0	-0.92	i	0.05	i
870.0	-0.89	i	0.07	i	1330.0	-0.93	i	0.13	i
880.0	-0.77	i	-0.04	i	1340.0	-0.78	i	-0.01	i
890.0	-0.72	i	-0.15	i	1350.0	-0.94	i	0.03	i
900.0	-0.82	i	-0.06	i	1360.0	-0.75	i	-0.07	i
910.0	-0.98	i	-0.07	i	1370.0	-0.78	i	-0.13	i
920.0	-0.52	i	-0.35	i	1380.0	-0.83	i	0.07	i
930.0	-0.99	i	-0.02	i	1390.0	-0.70	i	0.04	i
940.0	-0.74	i	0.03	i	1400.0	-0.71	i	-0.04	i
950.0	-0.77	i	-0.05	i	1410.0	-0.66	i	0.04	i
960.0	-0.91	i	-0.01	i	1420.0	-0.73	i	-0.02	i
970.0	-0.90	i	-0.02	i	1430.0	-0.74	i	0.02	i
980.0	-0.92	i	-0.01	i	1440.0	-0.76	i	-0.02	i
990.0	-0.68	i	-0.15	i	1450.0	-0.78	i	0.07	i
1000.0	-0.71	i	0.01	i	1460.0	-0.73	i	0.00	i
1010.0	-0.62	i	0.07	i	1470.0	-0.74	i	-0.06	i
1020.0	-0.56	i	-0.07	i	1480.0	-0.86	i	-0.13	i
1030.0	-0.61	i	-0.07	i	1490.0	-1.05	ii	0.07	i
1040.0	-0.70	i	-0.08	i	1500.0	-1.21	ii	0.19	i
1050.0	-0.81	i	-0.03	i	1510.0	-0.98	i	-0.06	i
1060.0	-0.73	i	-0.06	i	1520.0	-1.08	ii	-0.02	i
1070.0	-0.86	i	0.09	i	1530.0	-0.97	i	-0.03	i
1080.0	-0.74	i	0.02	i	1540.0	-1.19	ii	-0.01	i
1090.0	-0.70	i	0.00	i	1550.0	-0.97	i	-0.03	i
1100.0	-0.56	i	-0.05	i	1560.0	-0.79	i	-0.15	i
1110.0	-0.59	i	0.02	i	1570.0	-1.16	ii	0.06	i
1120.0	-0.62	i	0.04	i	1580.0	-1.29	ii	0.14	i
1130.0	-0.64	i	-0.02	i	1590.0	-1.15	ii	-0.04	i
1140.0	-0.51	i	-0.03	i	1600.0	-1.15	ii	-0.03	i
1150.0	-0.57	i	-0.09	i	1610.0	-1.10	ii	0.07	i
1160.0	-0.60	i	-0.11	i	1620.0	-1.01	ii	-0.03	i
1170.0	-0.72	i	0.02	i	1630.0	-1.26	ii	-0.06	i
1180.0	-0.72	i	0.04	i	1640.0	-0.98	i	-0.03	i
1190.0	-0.70	i	-0.03	i	1650.0	-0.96	i	-0.06	i
1200.0	-0.61	i	0.03	i	1660.0	-0.56	i	-0.21	i
1210.0	-0.60	i	-0.06	i	1670.0	-0.04	i	-0.55	i
1220.0	-0.61	i	0.00	i	1680.0	1.55	i	-0.57	i
1230.0	-0.56	i	0.01	i	1690.0	0.49	i	-1.26	i
1240.0	-0.54	i	-0.05	i	1700.0	-0.60	i	-0.93	i
1250.0	-0.59	i	-0.02	i					

* Verification status legend:
i) Within specifications;
ii) Within specifications: All measured results are within specification limits. In conformance with ISO/IEC 17025, full compliance cannot be stated because of measurement uncertainties. Nevertheless, results indicate that the instrument is likely to perform according to specifications;
iii) Outside specifications: Some measured results are outside specification limits. Nevertheless, as per ISO/IEC 17025, non compliance cannot be stated because of measurement uncertainties;
iv) Outside specifications.
Unless otherwise stated, 100 % of shipped units have all "As left" results in case "i".

Figure 3. Calibration Certificate (page 2)

c. The allowed deviation is the difference between the measurement of the power meter under test and the reference standard; this is a key factor in the determination of whether or not a unit conforms to its specifications.

d. The conformance assessment of the power meter's status upon reception of the unit requires a judgement on the compliance or non-compliance with specifications. The result of this judgement depends on the allowed deviation and on the gray zone introduced by calibration uncertainties. As a consequence of this gray zone, it is not always possible to draw a firm conclusion regarding the status of the unit when it is received from the customer.

Aware of the importance of this step, and following the indications given by ISO/IEC 17025, EXFO introduced, in the "As found" section of the certificates, four possible conclusions depending on deviation, guaranteed specifications (Spec) and calibration uncertainty (Ucal):

i. **Within specifications**

When measured deviation is within the following limits, the unit is said to be within specifications with a level of confidence of 95 %:

$$|\text{deviation}| \leq \text{Spec} - U_{cal}$$

ii. **Within specifications***

This is stated when all measured results are within specification limits. In conformance with ISO/IEC 17025, full compliance cannot be stated because of measurement uncertainties. Nevertheless, results indicate that the instrument is likely to perform according to specifications.

This zone is bound by the following limits:

$$\text{Spec} - U_{cal} < |\text{deviation}| \leq \text{Spec}$$

iii. **Outside specifications***

This is the case when some measured results are outside specification limits. Nevertheless, non compliance cannot be stated because of measurement uncertainties.

Limits are given by:

$$\text{Spec} < |\text{deviation}| \leq \text{Spec} + U_{cal}$$

In cases where conclusion ii or iii applies to the instrument, it is up to the user to determine if measurements taken prior to the sending of the unit for verification are considered to be valid or not. This depends on the following factors:

- Whether a deviation larger than published specifications can be tolerated for these measurements
- The closeness of the measurements that were taken with the unit to the maximum allowed deviation

iv. **Outside specifications**

In this case, the unit is definitely not within specifications, as deviation is higher than the sum of the specification and the calibration uncertainty.

$$|\text{deviation}| > \text{Spec} + U_{cal}$$

For example, for power meter models whose specification and calibration uncertainties are respectively 5 %[1] and 4 % (at 1550 nm), the deviation will allow us to conclude the following:

i. Within specifications: $|\text{deviation}| \leq 1$ %

ii. Within specifications*: 1 % $<|\text{deviation}| \leq$ 5 %

iii. Outside specifications*: 5 % $<|\text{deviation}| \leq$ 9 %

iv. Outside specifications: $|\text{deviation}| >$ 9 %

1 Note that when converting a linear ratio of error (W/W) to logarithmic scale (dB), the following formula shall be followed: $U_{dB} = 10\ log_{10}\ (1 + U_{lin})$
The result in logarithmic scale depends on which limit is taken on the linear scale, e.g.: for +5 %, the equivalent is 0.21 dB; whereas for −5 %, the equivalent is −0.22 dB.

This approach reflects recommendations given by some European standards, which state that once the result of a calibration is found to be in the gray zone, statistically, it is still possible that the unit is within specifications. Probabilities increase or decrease depending on the measured deviation compared to calibration uncertainties and specifications.

For further information, refer to AFNOR NF X 07-010 (**Association Française de Normalisation**): *The Metrology Function within the Firm* and to ILAC-G8:1996 (International Laboratory Accreditation Cooperation): *Guidelines on Assessment and Reporting of Compliance with Specifications*.

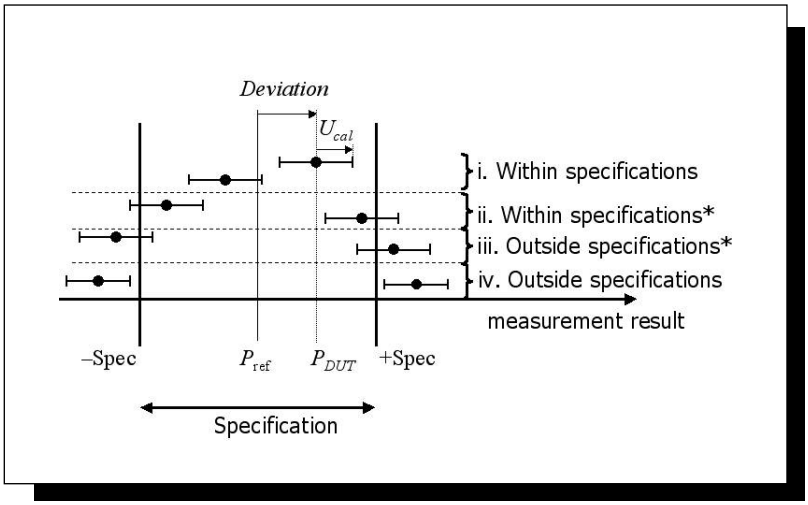

Figure 4. Decision on conformity

Dedicated Software and Database Architecture

A considerable amount of effort was deployed by a dedicated team of software specialists to design and develop fully integrated and automated calibration software. This software controls all components of EXFO's in-house system, statistically processing all measurements and ensuring a high level of confidence for every result.

One of the main advantages of this system is the implementation of a database that enables EXFO to keep track of all calibrations and verifications, thus providing two key benefits. First, to relate any calibration to the working and reference standards used. Second, to keep a statistical record of power and wavelength calibrations of working standards. This rigorous process ensures the highest quality for all calibrations performed at each station.

Acknowledgements

I would especially like to thank my colleagues Marc Breton and Francis Regamey for their precious collaboration. Their advice and direction were particularly valuable during the metrological research and required tests. It is also important to mention the great effort put forth by the entire software team in the design and development of this system.

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