

Calibration of fibre-optic power meters

The European Standard EN 61315:2006 has the status of a
British Standard

ICS 33.140; 33.180.10

National foreword

This British Standard is the official English language version of EN 61315:2006. It is identical with IEC 61315:2005. It supersedes BS EN 61315:1997 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/86, Fibre optics, which has the responsibility to:

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English version

Calibration of fibre-optic power meters
(IEC 61315:2005)

Etalonnage de wattmètres pour dispositifs
à fibres optiques
(CEI 61315:2005)

Kalibrierung von Lichtwellenleiter-
Leistungsmessern
(IEC 61315:2005)

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Foreword

The text of document 86/239/FDIS, future edition 2 of IEC 61315, prepared by IEC TC 86, Fibre optics, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61315 on 2005-11-01.

This European Standard supersedes EN 61315:1997.

Changes from EN 61315:1997 consist of adapting the uncertainty calculations to the approach taken by the GUM, and adapting the terminology and graphical symbology to international standards VIM, IEC 61931 and IEC 61930.

The importance of the nonlinearity calibration is emphasized by giving more detail and is now in a separate clause.

Requirements concerning organization and traceability have been taken out of this standard since they are general requirements concerning calibration laboratories and are given in EN ISO/IEC 17025.

The goal to standardize the type of power meter specifications has been removed since it does not belong in a standard on calibration. Specifications should, however, still be based on calibrations made following this standard and EN 60359.

The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement (dop) 2006-08-01
- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2008-11-01

Endorsement notice

The text of the International Standard IEC 61315:2005 was approved by CENELEC as a European Standard without any modification.

CONTENTS

INTRODUCTION	4
1 Scope	5
2 Normative references	5
3 Terms and definitions	6
4 Preparation for calibration	13
4.1 Organization.....	13
4.2 Traceability	13
4.3 Advice for measurements and calibrations	14
4.4 Recommendations to customers	15
5 Absolute power calibration.....	15
5.1 Establishing the calibration conditions	16
5.2 Calibration procedure	17
5.3 Calibration uncertainty.....	18
5.4 Reporting the results	25
6 Measurement uncertainty of a calibrated power meter.....	25
6.1 Uncertainty at reference conditions.....	25
6.2 Uncertainty at operating conditions	26
7 Nonlinearity calibration	33
7.1 Nonlinearity calibration based on superposition	34
7.2 Nonlinearity calibration based on comparison with a calibrated power meter	36
7.3 Nonlinearity calibration based on comparison with an attenuator	37
7.4 Calibration of power meter for high power measurement	37
Annex A (normative) Mathematical basis.....	39
A.1 Type A evaluation of uncertainty	39
A.2 Type B evaluation of uncertainty	39
A.3 Determining the combined standard uncertainty	40
A.4 Reporting	41
Figure 1 – Typical spectral responsivity of photoelectric detectors	11
Figure 2 – Example of a traceability chain	13
Figure 3 – Measurement setup for sequential, fibre-based calibration	16
Figure 4 – Change of conditions and uncertainty	21
Figure 5 – Determining and recording an extension uncertainty	27
Figure 6 – Possible subdivision of the optical reference plane into 10 x 10 squares, for the measurement of the spatial response	28
Figure 7 – Wavelength dependence of response due to Fabry-Perot type interference	32
Figure 8 – Measurement setup of polarization dependent response	32
Figure 9 – Nonlinearity calibration based on superposition	34
Figure 10 – Measurement setup for nonlinearity calibration by comparison	36
Table 1 – Typical calibration methods and correspondent power	15
Table 2 – Nonlinearity	35

INTRODUCTION

Fibre-optic power meters are designed to measure optical power from fibre-optic sources as accurately as possible. This capability depends largely on the quality of the calibration process. In contrast to other types of measuring equipment, the measurement results of fibre-optic power meters usually depend on many conditions of measurement. The conditions of measurement during the calibration process are called *calibration conditions*. Their precise description must therefore be an integral part of the calibration.

This International Standard defines all of the steps involved in the calibration process: establishing the *calibration conditions*, carrying out the calibration, calculating the uncertainty, and reporting the uncertainty, the *calibration conditions* and the *traceability*.

The absolute power calibration describes how to determine the ratio between the value of the input power and the power meter's result. This ratio is called *correction factor*. The measurement uncertainty of the correction factor is combined following Annex A from uncertainty contributions from the reference meter, the test meter, the setup and the procedure.

The calculations go through detailed characterizations of individual uncertainties. It is important to know that:

- a) estimations of the individual uncertainties are acceptable;
- b) a detailed uncertainty analysis is only necessary once for each power meter type under test, and all subsequent calibrations can be based on this one-time analysis, using the appropriate type A measurement contributions evaluated at the time of the calibration;
- c) some of the individual uncertainties can simply be considered to be part of a checklist, with an actual value which can be neglected.

Calibration according to Clause 5 is mandatory for reports referring to this standard.

Clause 6 describes the evaluation of the measurement uncertainty of a calibrated power meter operated within *reference conditions* or within *operating conditions*. It depends on the calibration uncertainty of the power meter as calculated in 5.3, the conditions and its dependence on the conditions. It is usually performed by manufacturers in order to establish specifications and is not mandatory for reports referring to this standard. One of these dependences, the nonlinearity, is determined in a separate calibration (Clause 7).

NOTE Fibre-optic power meters measure and indicate the optical power in the air, at the end of an optical fibre. It is about 3,6 % lower than in the fibre due to Fresnel reflection at the glass-air boundary (with $N = 1,47$). This should be kept in mind when the power in the fibre has to be known.

CALIBRATION OF FIBRE-OPTIC POWER METERS

1 Scope

This international standard is applicable to instruments measuring radiant power emitted from sources which are typical for the fibre-optic communications industry. These sources include laser diodes, light emitting diodes (LEDs) and fibre-type sources. The radiation may be divergent or collimated. The standard describes the calibration of power meters to be performed by calibration laboratories or by power meter manufacturers.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-300, *International Electrotechnical Vocabulary – Electrical and electronic measurements and measuring instruments – Part 311: General terms relating to measurements – Part 312: General terms relating to electrical measurements – Part 313: Types of electrical measuring instruments – Part 314: Specific terms according to the type of instrument*

IEC 60359, *Electrical and electronic measurement equipment – Expression of performance*

IEC 60793-2, *Optical fibres – Part 2: Product specifications – General*

IEC 61300-3-12, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-12: Examinations and measurements – Polarization dependence of attenuation of a single-mode fibre optic component: Matrix calculation method*

IEC 61930, *Fibre optic graphical symbology*

IEC 61931, *Fibre optic – Terminology*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, and OIML:1993, *International vocabulary of basic terms in metrology (VIM)*

BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, and OIML:1995, *Guide to the expression of uncertainty in measurement (GUM)*

3 Terms and definitions

For the purposes of this International Standard, the definitions contained in IEC 61931 and the following definitions apply.

3.1

accredited calibration laboratory

a calibration laboratory authorized by the appropriate national organization to issue calibration certificates with a minimum specified uncertainty, which demonstrate traceability to *national standards*

3.2

adjustment

set of operations carried out on an instrument in order that it provides given indications corresponding to given values of the measurand

[IEV 311-03-16; see also VIM 4.30]

NOTE When the instrument is made to give a null indication corresponding to a null value of the measurand, the set of operations is called **zero adjustment**

3.3

calibration

set of operations that establish, under specified conditions, the relationship between the values of quantities indicated by a measuring instrument and the corresponding values realized by standards

[VIM, 6.11, modified]

NOTE 1 The result of a calibration permits either the assignment of values of measurands to the indications or the determination of corrections with respect to indications.

NOTE 2 A calibration may also determine other metrological properties such as the effect of influence quantities.

NOTE 3 The result of a calibration may be recorded in a document, sometimes called a **calibration certificate** or a **calibration report**.

3.4

calibration conditions

conditions of measurement in which the calibration is performed

3.5

centre wavelength

λ_{centre}

the power-weighted mean wavelength of a light source in vacuum.

For a continuous spectrum the centre wavelength is defined as:

$$\lambda_{\text{centre}} = \frac{1}{P_{\text{total}}} \int p(\lambda) \times \lambda \times d\lambda$$

and the total power is:

$$P_{\text{total}} = \int p(\lambda) \times d\lambda$$

where $p(\lambda)$ is the power spectral density of the source, for example in W/nm.

For a spectrum consisting of discrete lines, the centre wavelength is defined as:

$$\lambda_{\text{centre}} = \frac{\sum P_i \times \lambda_i}{\sum P_i}$$

where

P_i is the power of the i^{th} discrete line, for example in W, and

λ_i is the vacuum wavelength of the i^{th} discrete line.

NOTE The above integrals and summations theoretically extend over the entire spectrum of the light source, however it is usually sufficient to perform the integral or summation over the spectrum where the spectral density $p(\lambda)$ or power P_i is higher than 0,1 % of the maximum spectral density $p(\lambda)$ or power P_i .

3.6

correction factor

CF

numerical factor by which the uncorrected result of a measurement is multiplied to compensate for systematic error

[VIM, 3.16]

3.7

decibel

dB

submultiple of the bel (1 dB = 0,1 B), unit used to express values of power level on a logarithmic scale. The **power level** is always relative to a reference power P_0 :

$$L_{P/P_0} = 10 \times \log_{10} \left(\frac{P}{P_0} \right) \text{ (dB)}$$

where P and P_0 are expressed in the same linear units.

The reference power must always be reported, for example, the power level of 200 μW relative to 1 mW can be noted $L_{P/1 \text{ mW}} = -7 \text{ dB}$ or $L_P(\text{re } 1 \text{ mW}) = -7 \text{ dB}$.

The linear ratio, R_{lin} , of two radiant powers, P_1 and P_2 , can alternatively be expressed as a **power level difference** in decibels (dB):

$$\Delta L_P = 10 \log_{10}(R_{\text{lin}}) = 10 \log_{10}(P_1/P_2) = 10 \log_{10}(P_1) - 10 \log_{10}(P_2).$$

Similarly, relative uncertainties, U_{lin} , or relative deviations, can be alternatively expressed in decibels:

$$U_{\text{dB}} = \frac{10}{\ln 10} U_{\text{lin}} \cong 4,34 \times U_{\text{lin}} \text{ (dB)}$$

NOTE ISO 31-2 and IEC 60027-3 should be consulted for further details. The rules of IEC 60027-3 do not permit attachments to unit symbols. However, the unit symbol dBm is widely used to indicate power levels relative to 1 mW and often displayed by fibre-optic power meters.

3.8

detector

the element of the power meter that transduces the radiant optical power into a measurable, usually electrical, quantity. In this standard, the detector is assumed to be connected with the optical input port by an optical path

[see IEC 61931 and VIM, 4.15]

3.9**deviation*****D***

for the purpose of this standard, the relative difference between the power measured by the test meter P_{DUT} and the reference power P_{ref}

$$D = \frac{P_{\text{DUT}} - P_{\text{ref}}}{P_{\text{ref}}}$$

3.10**excitation (fibre)**

a description of the distribution of optical power between the modes in the fibre. In context with multimode fibres, the fibre excitation is described by:

- a) the *spot diameter* on the surface of the fibre end, and
- b) the *numerical aperture* of the radiation emitted from the fibre.

Full excitation means radiation characterized by a spot diameter which is approximately equal to the fibre's core diameter, and by a numerical aperture which is approximately equal to the fibre's numerical aperture.

Single mode fibres are generally assumed to be excited by only one mode (the fundamental mode)

3.11**instrument state**

set of parameters that can be chosen on an instrument

NOTE Typical parameters of the instrument state are the optical power range, the wavelength setting, the display measurement unit and the output from which the measurement result is obtained (for example display, interface bus, analogue output).

3.12**irradiance**

the quotient of the incremental radiant power ∂P incident on an element of the reference plane by the incremental area ∂A of that element:

$$E = \frac{\partial P}{\partial A} \text{ (W/m}^2\text{)}$$

[IEC 61931, definition 2.1.15, modified]

3.13**measurement result*****y***

(displayed or electrical) output of a power meter (or standard), after completing all actions suggested by the operating instructions, for example warm-up, zeroing and wavelength-correction, expressed in watts (W). For the purpose of uncertainty analysis, measurement results in other units, for example volts, should be converted to watts. Measurement results in decibels (dB) should also be converted to watts, because the entire uncertainty accumulation is based on measurement results expressed in watts.

3.14**measuring range**

set of values of measurands for which the error of a measuring instrument is intended to lie within specified limits

[VIM, 5.4]

NOTE In this standard, the measuring range is the range of radiant power (part of the *operating range*), for which the uncertainty at operating conditions is specified. The term "dynamic range" should be avoided in this context.

3.15

national (measurement) standard

standard recognized by a national decision to serve, in a country, as the basis for assigning values to other standards of the quantity concerned

[VIM, 6.3]

3.16

national standards laboratory

laboratory which maintains the *national standard*

3.17

nonlinearity

NL

relative difference between the *response* at a given power *P* and the response at a reference power *P*₀:

$$nl_{P/P_0} = \frac{r(P)}{r(P_0)} - 1$$

If expressed in decibels, the nonlinearity is:

$$NL_{P/P_0} = 10 \times \log_{10} \frac{r(P)}{r(P_0)} \text{ (dB)}$$

NOTE 1 The nonlinearity is equal to zero at the reference power.

NOTE 2 The term "local nonlinearity" is used for the relative difference between the responses at two different power levels (separated by 3,01 dB) obtained during the nonlinearity calibration. The term "global nonlinearity" is used for the result of summing up the local nonlinearities; it is identical to the nonlinearity defined here.

3.18

numerical aperture

description of the beam divergence of an optical source. In this standard, the numerical aperture is the sine of the (linear) half-angle at which the irradiance is 5 % of the maximum irradiance.

NOTE This definition was adopted from the definition of the numerical aperture of multimode graded-index fibres in IEC 60793-1-43. In this standard, the definition is used to describe the divergence of **all** divergent beams.

3.19

operating conditions

appropriate set of specified ranges of values of influence quantities usually wider than the reference conditions for which the uncertainties of a measuring instrument are specified (see VIM, 5.5)

NOTE The operating conditions and uncertainty at operating conditions are usually specified by manufacturer for the convenience of the user.

3.20

operating range

specified range of values of one of a set of *operating conditions*

3.21**optical input port**

physical input of the power meter (or standard) to which the radiant power is to be applied or to which the optical fibre end is to be connected. An optical path (path of rays with or without optical elements like lenses, diaphragms, light guides, etc.) is assumed to connect the optical input port with the power meter's detector.

3.22**optical reference plane**

plane on or near the *optical input port* which is used to define the beam's *spot diameter*

NOTE The optical reference plane is usually assumed to be perpendicular to the beam propagation, and it should be described by appropriate mechanical dimensions relative to the power meter's optical input port.

3.23**polarization dependent response****PDR**

variation in response of a power meter with respect to all possible polarization states of the input light, expressed in decibels:

$$PDR = 10 \times \log_{10} \left(\frac{r_{\max}}{r_{\min}} \right) \text{ (dB)}$$

where $r_{\max}$ and $r_{\min}$ are the maximum and minimum response taken over all polarization states.

3.24**power meter (fibre-optic)**

in this standard, instrument capable of measuring radiant power from sources which are typical for the fibre-optic communications industry. These sources include laser diodes, LEDs and fibres. The radiation may be divergent or collimated. The radiation is assumed to be incident on the optical reference plane within the specified conditions. A power meter may consist either of a single instrument or a main instrument and a separate sensing head. In the case of a separate sensing head, the head may be calibrated without the main instrument.

NOTE 1 The measurement result may be influenced by the main instrument, particularly if any analog electronics is used in the main instrument. In such cases, the sensing head must be calibrated together with the main instrument.

NOTE 2 A fibre-optic power meter is usually capable of measuring the time-average of **modulated** optical power. An increased uncertainty may be observed, which depends on the duty cycle and the peak power of modulated optical power.

NOTE 3 All of the standards in this standard are power meters.

3.25**radiant power****P**

power emitted, transferred, or received in the form of optical radiation [1]¹⁾. Unit: W.

3.26**reference conditions**

conditions of use prescribed for testing the performance of a measuring instrument or for intercomparison of results of measurements

[VIM, 5.7]

¹⁾ Figures in square brackets refer to the Bibliography.

NOTE The reference conditions generally include **reference values** or **reference ranges** for the influence quantities affecting the measuring instrument.

3.27

reference meter

standard which is used as the reference for the *calibration* of a *test meter*

3.28

reference standard

standard, generally having the highest metrological quality available at a given location or in a given organization, from which measurements made there are derived

[VIM, 6.6]

3.29

response

r

measurement result of a power meter, *y*, divided by the radiant power on the power meter's optical reference plane, *P*, at a given condition of measurement:

$$r = \frac{y}{P} \text{ (W/W, dimensionless)}$$

NOTE An ideal power meter exhibits a response of 1 for all operating conditions.

3.30

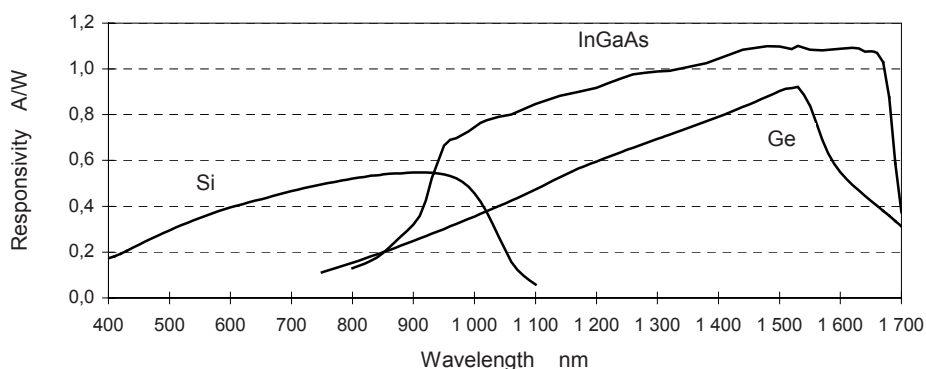
(spectral) responsivity

R

quotient of the detector output current *I* by the incident monochromatic optical power *P*:

$$R = \frac{I}{P} \text{ (A/W)}$$

NOTE The responsivity depends on the conditions (wavelength, temperature, etc.).



IEC 1826/05

Key

Si: silicon

Ge: germanium

InGaAs: indium gallium arsenide

Figure 1 – Typical spectral responsivity of photoelectric detectors

3.31**spectral bandwidth*****B***

for the purpose of this standard, full-width at half-maximum (FWHM) of the spectrum

If the spectrum is non-continuous, for example as in the case of a laser diode with a multi-longitudinal line spectrum, then the spectral bandwidth is defined with the help of the root-mean-square spectral bandwidth, B_{rms} :

$$B = M \times B_{\text{rms}} = M \sqrt{\frac{\sum_i P_i \times \lambda_i^2}{\sum_i P_i} - \lambda_{\text{centre}}^2} = M \sqrt{\frac{\sum_i P_i (\lambda_i - \lambda_{\text{centre}})^2}{\sum_i P_i}}$$

where

$M = 2\sqrt{2\ln 2} \cong 2,35$ (calculated using a spectrum with a Gaussian envelope);

P_i is the power of the i^{th} discrete line, for example in W;

λ_i is the vacuum wavelength of the i^{th} discrete line;

λ_{centre} is the *centre wavelength*.

NOTE 1 If the source emits at one wavelength only (single-line spectrum), it may be sufficient to specify an upper limit, for example spectral bandwidth < 1 nm.

NOTE 2 It is usually sufficient to perform the integral or summation over the spectrum where the power is higher than 0,1 % of the maximum power.

3.32**spot diameter**

in this standard, diameter of the irradiated area on the optical reference plane, defined by the (best-approximation) circle at which the *irradiance* has dropped to 5 % of the peak irradiance

NOTE 1 The ratio of 5 % was adopted for reasons of compatibility with the definition of the numerical aperture. Other ratios are often used to describe laser beams, for example $1/e^2$ or $1/e$. In that case it shall be stated with the spot diameter value.

NOTE 2 The diameter of the *optical reference plane* must be larger than the spot diameter in order to measure the whole optical power.

3.33**test meter**

power meter (or standard) to be calibrated by comparison with the *reference meter*

3.34**traceability**

property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties

[VIM, 6.10]

3.35**traceability chain**

unbroken chain of comparison

[VIM 6.10]