

INTERNATIONAL STANDARD

NORME INTERNATIONALE



Calibration of fibre-optic power meters

Étalonnage de wattmètres pour dispositifs à fibres optiques



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

CALIBRATION OF FIBRE-OPTIC POWER METERS

FOREWORD

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International Standard IEC 61315 has been prepared by IEC technical committee 86: Fibre optics.

This third edition cancels and replaces the second edition published in 2005. It constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) update of terms and definitions;
- b) update of 5.1, including Table 1 (new type of source);
- c) update of Annex A;
- d) addition of Annex B on dB conversion.

The text of this International Standard is based on the following documents:

CDV	Report on voting
86/533/CDV	86/540A/RVC

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

In this document, the following print types are used:

– *terms defined in the document: in italic type.*

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- withdrawn,
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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 is therefore an integral part of the *calibration*.

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

Clause 5 defines absolute power *calibration*, which is mandatory for *calibration* reports referring to this document.

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 5.4, 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 document. One of these dependences, the *nonlinearity*, is determined in a separate *calibration* (Clause 7).

CALIBRATION OF FIBRE-OPTIC POWER METERS

1 Scope

This document is applicable to instruments measuring *radiant power* emitted from sources that are typical for the fibre-optic communications industry. These sources include laser diodes, light emitting diodes (LEDs) and fibre-type sources. Both divergent and collimated radiations are covered. This document defines the *calibration* of power meters to be performed by *calibration* laboratories or by power meter manufacturers.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60793-2, *Optical fibres – Part 2: Product specifications – General*

IEC TR 61931:1998, *Fibre optic – Terminology*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TR 61931 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

accredited calibration laboratory

calibration laboratory authorized by the appropriate national organization to issue *calibration* certificates with a minimum specified uncertainty, which demonstrate *traceability* to *national standards* (3.14)

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

Note 1 to entry: 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.

Note 2 to entry: For more information, see ISO/IEC Guide 99:2007, 3.11.

[SOURCE: IEC 60050-311:2001, 311-03-16, modified – The words "of a measuring instrument" have been deleted from the term, and Note 2 to entry has been added.]

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 measurement standards

Note 1 to entry: 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 to entry: A *calibration* may also determine other metrological properties such as the effect of influence quantities.

Note 3 to entry: The result of a *calibration* may be recorded in a document, sometimes called a *calibration certificate* or a *calibration report*.

Note 4 to entry: See also ISO/IEC Guide 99:2007, 2.39.

3.4 calibration conditions

conditions of measurement in which the *calibration* is performed

3.5 centroidal wavelength

λ_c
power-weighted mean wavelength of a light source in vacuum

Note 1 to entry: For a continuous spectrum, the *centroidal wavelength* is defined as:

$$\lambda_c = \frac{\int p(\lambda) \lambda d\lambda}{P_{\text{total}}} \quad (1)$$

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

$$\lambda_c = \frac{\sum_i P_i \lambda_i}{\sum_i P_i} \quad (2)$$

where

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

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

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

P_{total} is the total power, for example, in W.

Note 2 to entry: 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

Note 1 to entry: This note applies to the French language only.

3.7 detector

element of the power meter that transduces the radiant optical power into a measurable, usually electrical, quantity

Note 1 to entry: In this document, the *detector* is assumed to be connected with the *optical input port* by an optical path.

Note 2 to entry: For more information, see ISO/IEC Guide 99:2007, 3.9.

3.8 deviation

D

relative difference between the power measured by the *test meter* (3.32) P_{DUT} and the reference power P_{ref} :

$$D = \frac{P_{\text{DUT}} - P_{\text{ref}}}{P_{\text{ref}}} \quad (3)$$

Note 1 to entry: This note applies to the French language only.

3.9 excitation

<fibre> description of the distribution of optical power between the modes in the fibre

Note 1 to entry: In context with multimode fibres, the fibre *excitation* is described by

- the *spot diameter* (3.31) on the surface of the fibre end, and
- the *numerical aperture* (3.17) of the radiation emitted from the fibre.

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

3.10 instrument state

set of parameters that can be chosen on an instrument

Note 1 to entry: 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).

3.11 irradiance

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

$$E = \frac{\partial P}{\partial A} \quad (\text{W/m}^2) \quad (4)$$

[Note 1 to entry: For more information, see IEC TR 61931:1998, 2.1.15.

3.12 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, zero adjustment and wavelength-correction

Note 1 to entry: *Measurement result* is expressed in watts (W). For the purposes of uncertainty, *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. See Annex B.

3.13

measuring range

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

Note 1 to entry: In this document, 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.

Note 2 to entry: For more information, see ISO/IEC Guide 99:2007, 4.7.

3.14

national measurement standard

national 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

Note 1 to entry: For more information, see ISO/IEC Guide 99:2007, 5.3.

3.15

national standards laboratory

laboratory which maintains the *national standard* (3.14)

3.16

nonlinearity

NL

relative difference between the *response* (3.28) at a given power *P* and the *response* at a reference power *P*₀:

$$nl_{P/P_0} = \frac{r(P)}{r(P_0)} - 1 \quad (5)$$

If expressed in decibels, the *nonlinearity* is:

$$NL_{P/P_0} = 10 \times \log_{10} \frac{r(P)}{r(P_0)} \quad (\text{dB}) \quad (6)$$

Note 1 to entry: The *nonlinearity* is equal to zero at the reference power.

Note 2 to entry: 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 the local nonlinearities (in dB); it is identical to the *nonlinearity* defined here.

3.17

numerical aperture

description of the beam divergence of an optical source

Note 1 to entry: In this document, the *numerical aperture* is the sine of the (linear) half-angle at which the *irradiance* is 5 % of the maximum *irradiance*.

Note 2 to entry: Adapted from the definition of the *numerical aperture* of multimode graded-index fibres in IEC 60793-1-43:2015, Clause 3; in this document, the definition is used to describe the divergence of all divergent beams.

3.18 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

Note 1 to entry: The *operating conditions* and uncertainty at *operating conditions* are usually specified by the manufacturer for the convenience of the user.

3.19 operating range

specified range of values of one of a set of *operating conditions* (3.18)

3.20 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

Note 1 to entry: An optical path (path of rays with or without optical elements, such as lenses, diaphragms, light guides, etc.) is assumed to connect the *optical input port* with the power meter's *detector*.

3.21 optical reference plane

plane on or near the *optical input port* (3.20) which is used to define the beam's *spot diameter* (3.31)

Note 1 to entry: 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*.

3.22 polarization dependent response PDR

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

$$PDR = 10 \times \log_{10} \left(\frac{r_{\max}}{r_{\min}} \right) \text{ (dB)} \quad (7)$$

where

r_{\max} and r_{\min} are the maximum and minimum *response* (3.28) taken over all polarization states

Note 1 to entry: *Polarization dependent response* is expressed in decibels.

Note 2 to entry: This note applies to the French language only.

3.23 fibre-optic power meter

instrument capable of measuring *radiant power* from fibre-coupled sources such as lasers and LEDs, which are typical for the fibre-optic communications industry

Note 1 to entry: The radiation may be divergent or collimated. The radiation is assumed to be incident on the *optical reference plane* within the specified conditions.

Note 2 to entry: A power meter may consist of either 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. However, if any analogue electronics are used in the main instrument, the sensing head shall be calibrated together with the main instrument.

Note 3 to entry: 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.

3.24 radiant power

P

power emitted, transferred, or received in the form of optical radiation [1]¹

Note 1 to entry: *Radiant power* is expressed in watts.

3.25 reference conditions

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

Note 1 to entry: The *reference conditions* generally include reference values or reference ranges for the influence quantities affecting the measuring instrument.

3.26 reference meter

standard which is used as the reference for the *calibration* (3.3) of a *test meter* (3.32)

3.27 reference standard

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

Note 1 to entry: For more information, see ISO/IEC Guide 99:2007, 5.6.

3.28 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:

$$r = \frac{y}{P} \text{ (W/W, dimensionless)} \quad (8)$$

Note 1 to entry: An ideal power meter exhibits a *response* of 1 for all *operating conditions*.

3.29 spectral responsivity responsivity

R

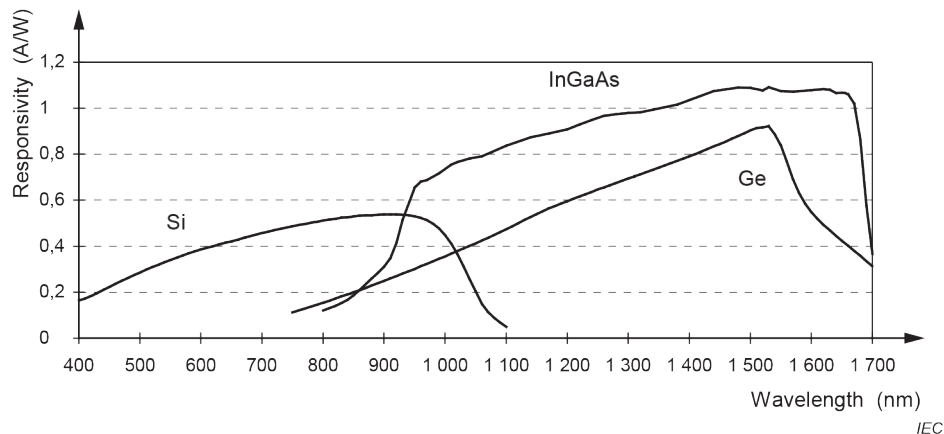
quotient of the *detector* output current I by the incident monochromatic optical power P :

$$R = \frac{I}{P} \text{ (A/W)} \quad (9)$$

Note 1 to entry: The *responsivity* depends on the conditions (wavelength, temperature, etc.). See Figure 1.

Note 2 to entry: This note applies to the French language only.

¹ Numbers in square brackets refer to the Bibliography.

**Key**

Si silicon

Ge germanium

InGaAs indium gallium arsenide

Figure 1 – Typical spectral responsivity of photoelectric detectors**3.30
spectral bandwidth***B*

full-width at half-maximum (FWHM) of the source spectrum

Note 1 to entry: If the source is a laser diode with a multiple-longitudinal mode spectrum, then the FWHM *spectral bandwidth* *B* is the RMS *spectral bandwidth*, multiplied by 2,35 (assuming the source has a Gaussian envelope):

$$B = 2,35 \sqrt{\frac{1}{P_{\text{total}}} \sum_i P_i (\lambda_i - \lambda_c)^2} \quad (10)$$

$$P_{\text{total}} = \sum_i P_i \quad (11)$$

where

 λ_c is the *centroidal wavelength* (3.5) of the laser diode, in nm; P_{total} is the total power, in W; P_i is the power of i^{th} longitudinal mode, in W; λ_i is the vacuum wavelength of i^{th} longitudinal mode, in nm.

Note 2 to entry: 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 3 to entry: 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.

Note 4 to entry: This note applies to the French language only.

**3.31
spot diameter**

diameter of the irradiated area on the *optical reference plane*, defined by the (best-approximation) circle at which the *irradiance* (3.11) has dropped to 5 % of the peak *irradiance*

Note 1 to entry: 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, the ratio shall be stated with the *spot diameter* value.

3.32
test meter

fibre-optic power meter (3.23) (or standard) to be calibrated by comparison with the *reference meter* (3.26)

3.33
traceability

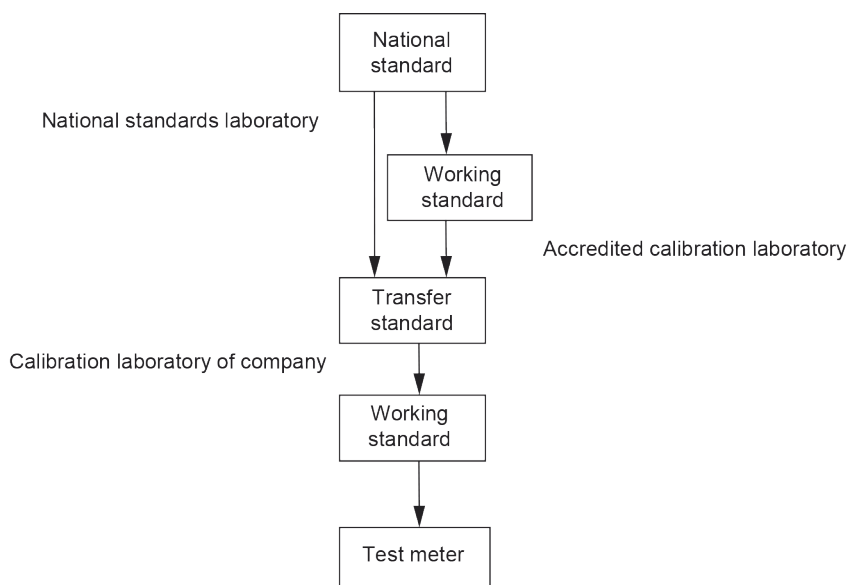
property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties

Note 1 to entry: For more information, see ISO/IEC Guide 99:2007, 2.41.

3.34
traceability chain

unbroken chain of comparison (see Figure 2)

Note 1 to entry: For more information, see ISO/IEC Guide 99:2007, 2.42.



IEC

Figure 2 – Example of a traceability chain

3.35
working standard

standard that is used routinely to calibrate or check measuring instruments

Note 1 to entry: A *working standard* is usually calibrated against a *reference standard* (3.27).

Note 2 to entry: For more information, see ISO/IEC Guide 99:2007, 5.7.

3.36
zero error

measurement result of a power meter without *irradiation* of the *optical input port*

Note 1 to entry: For more information, see ISO/IEC Guide 99:2007, 4.28.