

Calibration of fibre optic power meters

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National foreword

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

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- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 50, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Amendments issued since publication

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English version

Calibration of fibre optic power meters

(IEC 1315:1995)

Etalonnage des radiomètres pour sources
fibrées
(CEI 1315:1995)

Kalibrierung faseroptischer Leistungsmesser
(IEC 1315:1995)

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The text of the International Standard IEC 1315:1995, prepared by IEC TC 86, Fibre optics, was submitted to the formal vote and was approved by CENELEC as EN 61315 on 1997-03-11 without any modification.

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) 1998-03-01
- latest date by which the national standards conflicting with the EN have to be withdrawn (dow) 1998-03-01

Annexes designated “normative” are part of the body of the standard.

Annexes designated “informative” are given for information only.

In this standard, Annex A and Annex ZA are normative and Annex B is informative. Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 1315:1995 was approved by CENELEC as a European Standard without any modification.

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Section 1. General

1.1 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 parameters. A precise description of these parameters must therefore be an integral part of the calibration, because the specified uncertainty can only be valid for these “reference” conditions.

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

Another important goal is to create a standardized type of power meter specification, which will make it easier to compare power meters from different vendors.

The document is divided into four sections and two annexes.

Section 1. General

This contains the introduction, the scope, and the normative references.

Section 2. Basis for calibrations

This contains the definitions, the mathematical basis and general advice.

Section 3. Calibration at reference conditions

This describes how to determine the difference between the power meter measurement result and the “true” input power, and it outlines the calculation of the power meter uncertainty at reference conditions. The uncertainty analysis starts with the “uncertainty at reference conditions” of the national working standard. The “uncertainty at reference conditions” of the next lower level instrument is accumulated, by the root-sum-square method, from:

- 1) the “uncertainty at reference conditions” of the parent meter (that is of the standard used in the specific step of the calibration; at the beginning of the chain, the national working standard is the parent meter);
- 2) the transfer uncertainty of the parent meter, accumulated from individual **systematic**-type uncertainties of the transfer process which can be attributed to the parent meter (for example the ageing of the parent meter from the time of its original calibration to its usage in the present calibration, or the uncertainty caused by a change of beam geometry);
- 3) the transfer uncertainty of the test meter (that is of the next level power meter), again accumulated from individual **systematic** type uncertainties of the transfer process which can be attributed to the test meter (for example as caused by the uncertainty of the calibration wavelength);
- 4) the **random** uncertainty, calculated from the measured experimental standard deviation of the calibration process and the number of averages used in the calculation of the measurement results.

This is a repetitive process. It ends with the “uncertainty at reference conditions” of the test meter.

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

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

Calibration according to section 3 is mandatory for power meters compatible with this standard.

Section 4. Calibration for operating conditions

This describes the evaluation of the power meter dependences on the operating conditions. One of these dependences, the nonlinearity, is often determined in a separate calibration. The “operational dependences” are necessary for the evaluation of the uncertainty at reference conditions in section 3, and for the evaluation of the power meter total uncertainty in section 4.

The “total uncertainty” is calculated by adding, with the root-sum-square method, to the “uncertainty at reference conditions” all operational uncertainties, that is the worst case dependences of the measurement result on the operating conditions.

Determining the total uncertainty is not mandatory for power meters compatible with this document.

Annex A

This annex contains all of the forms, that is calibration certificates, traceability information, and calculation worksheets. These forms should be considered as suggestions only.

1.2 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 serves the purposes of calibrating single power meters and of setting specifications of power meters, to be performed by calibration laboratories or by the manufacturer of the power meter.

1.3 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 359:1987, *Expression of the performance of electrical and electronic measuring equipment*.

IEC 793-1:1992, *Optical fibres — Part 1: General specification*.

IEC 793-2:1992, *Optical fibres — Part 2: Product specifications*.

IEC 1040:1990, *Power and energy measuring detectors, instruments and equipment for laser radiation*.

Section 2. Basis of calibrations

2.1 Definitions

For the purposes of this International Standard, the following definitions apply.

2.1.1

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

2.1.2

accredited working standard

an optical power meter at the accredited calibration laboratory which is accredited by a national standards laboratory and is used for the calibration of power meters from customers outside the accredited calibration laboratory. It is assumed that the accredited working standard was calibrated from the national standard through an unbroken chain of comparisons

2.1.3

adjustment

modifying the hardware or the firmware of the test meter with the intention to make the measurement result of the test meter equal to the measurement result of the parent meter

2.1.4

calibration

the set of operations which establish, under specified conditions, the relationship between the values indicated by the measuring instrument and the corresponding known values of a measurand [Annex B, reference [1], 6.13]

NOTE The intention is to bring operating characteristics into substantial agreement with the scale of the national standards laboratory. In this standard, the term “calibration” is used for both “calibration at reference conditions” and “calibration for operating conditions”.

2.1.5

calibration at reference conditions

the calibration at reference conditions includes:

- a) the transfer (between the parent meter and the test meter); and
- b) the evaluation of the test meter uncertainty at reference conditions.

2.1.6

calibration for operating conditions

the calibration for operating conditions of a power meter includes the evaluation of the power meter operational uncertainty and the calculation of the power meter total uncertainty

2.1.7

calibration chain

an unbroken chain of transfers from the national working standard to the test meter

2.1.8

centre wavelength

for a given spectrum of an optical source, the centre wavelength λ_c is defined by the following integral, where the integration limits enclose the entire spectrum of the source:

$$\lambda_c = \frac{1}{P_o} \int p(\lambda) \lambda d\lambda \approx \frac{\sum P_i \lambda_i}{\sum P_i}$$

where

- $p(\lambda)$ is the spectral power density of the source, for example in watt/nm
- P_o is the total power, in watt
- λ_i are the discrete wavelength points, in the case that the spectrum is digitized
- P_i are the power levels at λ_i , in watt

2.1.9

(estimated) confidence level

probability that the true value of a measurand lies within a given interval (the uncertainty range)

NOTE For the sake of brevity, this standard mainly uses “confidence level” instead of “estimated confidence level”. In this standard, the confidence level is standardized to 95 %. An alternative confidence level of 99,7 % may be used, if specifically stated. See “**uncertainty range**” for further clarification.

2.1.10

correction factor

the numerical value by which the uncorrected measurement result is multiplied to compensate for an assumed individual error [modified from IEC 793-1, 3.15]

NOTE Depending on their origin, this standard distinguishes between, several types of correction factors. These are accumulated to a correction factor for the test meter, $CF_{\text{test meter}}$, which can either be recorded or adjusted to 1. For later use, the measurement result of the test meter should be multiplied by $CF_{\text{test meter}}$. Note that a correction factor expressed in decibels (dB) must be added to a measurement result expressed in dBm.

2.1.11

decibels (dB, dBm)

the linear ratio, R_{lin} , of two radiant power levels, P_1 and P_2 , can alternatively be expressed in dB (decibels) form. Similarly, **relative** uncertainties, U_{lin} , or relative deviations, can be alternatively expressed in dB form

Power ratio: $R_{\text{dB}} = 10 \log (R_{\text{lin}}) = 10 \log (P_1/P_2)$

Uncertainty: $U_{\text{dB}} = 10 \log (1 + U_{\text{lin}})$

absolute radiant power levels in watt units, P , can alternatively be expressed in dBm form (dBm = decibels relative to 1 milliwatt):

$$\text{Absolute power: } P_{\text{dBm}} = 10 \log (P/1 \text{ mW})$$

NOTE Note that for mathematical treatment, all measurement results should be expressed in watt units and all uncertainties should be expressed in linear form. This is recommended because the accumulation of uncertainties in logarithmic units is mathematically difficult. The final statement of an uncertainty may be in the linear or the dB form.

2.1.12 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

2.1.13 deviation

in this standard, the term deviation is used for a **known** relative offset, Δr , between a power meter response at a set of conditions, r , and its response at another set of conditions, r_o . When the response depends on various influence quantities x_i ($i = 1, 2, 3, \dots$), its relative deviation, which is caused only by the deviation Δx_i , is given approximately by:

$$\Delta r_i = \frac{1}{r_o} \frac{\delta r}{\delta x_i} \Delta x_i \quad [\text{dimensionless}]$$

the term is also used to quantify accumulated individual deviations

2.1.14 excitation (fibre)

a description of the distribution of optical power between the modes in the fibre. In the context of **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 core diameter, and by a numerical aperture which is approximately equal to the fibre numerical aperture **single-mode fibres** are generally assumed to be excited by only one mode (the fundamental mode)

2.1.15 extended reference conditions

a set of reference conditions which is derived from an original set of reference conditions, by changing one or more parameters of the original reference conditions, and by evaluating the test meter correction factor as caused by the change of parameters

NOTE With this concept, a power meter can be specified by uncertainty statements at more than one reference condition, without repeating the entire process of the calibration at reference conditions.

2.1.16 instrument state

a complete description of the state of the power meter during the calibration at reference conditions

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

2.1.17 irradiance

at a point of the surface of the optical reference plane, the quotient of the incremental radiant power δP incident on an element δA of the surface by the incremental area of that element. Symbol: E

$$E = \frac{\delta P}{\delta A} \quad [\text{Wm}^{-2}]$$

2.1.18**measurement result**

the (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, in watt units. Symbol: y . For the purpose of uncertainty analysis, measurement results in other units, for example volts, should be converted to watt. Measurement results in dBm (decibels relative to 1 mW) should also be converted to watt, because the entire uncertainty accumulation is based on measurement results in watt units

2.1.19**(specified) measuring range**

the set of values of a measurand for which the uncertainty of a measuring instrument is intended to lie within specified limits [modified from Annex B, reference [1], 5.04]

NOTE In this standard, the (specified) measuring range is the range of radiant power levels (part of the operating range), for which the total uncertainty is specified. The term “dynamic range” should be avoided in this context.

2.1.20**national standard**

a standard recognized by an official national decision as the basis for fixing the value, in a country, of all other standards of the quantity concerned [Annex B, reference [1], 6.07]

2.1.21**national working standard**

an optical power meter at the national standards laboratory which is either identical with the national standard or which was calibrated from the national standard through an unbroken chain of comparisons. The national working standard is used as the parent meter for the calibration of power meters from customers outside the national standards laboratory

2.1.22**national standards laboratory**

the laboratory which maintains the national standard and the national working standard

2.1.23**nominal wavelength**

a predefined wavelength used for specifying the uncertainty at reference conditions of a power meter

NOTE Note that the nominal wavelength (for example 1 300 nm or 1 500 nm) and the reference wavelength are often unequal: if a laser diode is used for the transfer, then the reference wavelength is given by the laser diode. The corresponding error of the power meter can be corrected with the concept of **extended reference conditions**.

2.1.24**non-linearity**

departure from linear response, that is the difference between the response at an arbitrary power level and the response at the reference power level, divided by the response at the reference power level

2.1.25**numerical aperture**

a 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 793-1. In this standard, the definition is used to describe the divergence of all divergent beams.

2.1.26**operating range**

all conditions of the measurand and of the influence quantities, and other important requirements, for which the total uncertainty of the power meter is intended to be met [modified from IEC 793-2, 5.05]

2.1.27**operational uncertainty**

either a partial uncertainty, that is the largest relative change of power meter response when changing one of the operating conditions within its specified operating range, or an accumulated uncertainty, by which several of the partial uncertainties are expressed

NOTE In this standard, operational uncertainties are to be treated as systematic uncertainties.

2.1.28 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 such as lenses, diaphragms, light guides, etc.) is assumed to connect the optical input port with the power meter detector

2.1.29 optical reference plane

a plane on or near the optical input port which is used to define the beam 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 optical input port.

2.1.30 parent meter

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

2.1.31 power meter (fibre optic)

in this standard, a power meter is an 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 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 level of modulated optical power.

NOTE 2 All of the standards in this standard are power meters. Often, the term “power meter” is used instead of “standard”.

2.1.32 radiant power

power emitted, transferred, or received in the form of optical radiation. Symbol: P . Unit: watt, W. The radiant power may also be expressed in the form of dBm (decibels relative to 1 milliwatt)

2.1.33 random uncertainty (uncertainty type A as specified by BIPM¹⁾)

a component of the uncertainty of measurement which, in the course of a number of measurements of the same measurand, varies in an unpredictable way. Note that it is not possible to correct for random uncertainty [modified from Annex B, [1], 3.12]

in this standard, random uncertainties are obtained from a series of measurements. They should be considered as relative uncertainties of the response of a power meter, that is response uncertainties relative to the response at reference conditions. They are assumed to be normally and symmetrically distributed about zero

random uncertainties should be expressed with the help of an (experimental) standard deviation, s_r , and with the number of measurements performed, n (The subscript “r” indicates “random”).

2.1.34 reference conditions

an appropriate set of influencing parameters, their nominal values and their tolerance bands, with respect to which the uncertainty at reference conditions is specified [modified from IEC 359, 4.9]. Note that each tolerance band includes both the possible uncertainty of the condition and the uncertainty in measuring the condition

in this standard, the conditions of the transfer to the test meter are termed “reference conditions”. Typically, several consecutive transfers are necessary to calibrate the test meter (calibration chain). Accordingly, there are several sets of reference conditions, all of which may be different

¹⁾ Bureau International des Poids et Mesures.

the reference conditions normally include the following parameters and, if necessary, their tolerance bands: reference date, reference temperature, reference power level, reference beam geometry or reference fibre, reference connector-adaptor combination, reference wavelength and reference (spectral) bandwidth. All possible states of polarization are included by default

2.1.35

reference standard

a standard, generally of the highest metrological quality available at a given location, from which measurements made at that location are derived [Annex B, [1], 6.08]

2.1.36

response, spectral response

the measurement result of a power meter or standard, $y(\lambda)$, divided by the radiant power on the power meter optical reference plane, $P(\lambda)$, at a wavelength λ , as a function of the wavelength. Symbol: $r(\lambda)$

$$r(\lambda) = y(\lambda)/P(\lambda) \quad [\text{W/W, dimensionless}]$$

NOTE Note that an ideal power meter exhibits a spectral response of 1. Also note that the adjective “spectral” is often omitted in the text, as well as the parameter λ .

2.1.37

spectral bandwidth

for the purpose of this standard, the spectral bandwidth is defined as the full-width-half-maximum (FWHM) spectral bandwidth. Symbol: B

if the spectrum is non-continuous, for example as in the case of a laser diode with a multilongitudinal line spectrum, then the spectral bandwidth is defined with the help of the r.m.s. spectral bandwidth, B_{RMS} :

$$B = M B_{\text{RMS}} = M \sqrt{\frac{\sum P_i \lambda_i^2}{P_o} - \lambda_c^2}$$

where

$$M = 2,35^a$$

λ_c is the centre wavelength

$$P_o = \sum P_i = \text{total power}$$

P_i is the power of i^{th} line

λ_i is the wavelength of i^{th} line

^a M is fixed at 2,35 for the purpose of standardization. The number 2,35 was calculated using a spectrum with a Gaussian envelope.

NOTE 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.

2.1.38

spot diameter

in this standard, the 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 This definition was adopted from the definition of the numerical aperture, for reasons of compatibility.

2.1.39

standard

all optical power meters in the calibration chain, except for the last one, are termed “standard”

2.1.40

systematic uncertainty (uncertainty type B as specified by BIPM)

a component of the uncertainty of measurement which, in the course of a number of measurements of the same measurand remains constant, or varies in a predictable way. Note that systematic uncertainties and their causes may be known or unknown [modified from Annex B, [1], 3.13]

NOTE Systematic uncertainties should be evaluated on the basis of known dependence of a measurement result on an influencing parameter, or based on experience with the measurement apparatus and the test meter. In this standard, systematic uncertainties are usually assumed to be:

- 1) uncertainties of the response of a power meter relative to the response at reference conditions;
- 2) independent of each other;

- 3) characterized by a rectangular (uniform) distribution;
- 4) specified in the form of either in uncertainty band, or an equivalent standard deviation. See Figure 1.

2.1.41

test meter

in the process of calibration at reference conditions, the power meter (or standard) to be calibrated, using a parent meter as the reference

2.1.42

total uncertainty

for the specified operating conditions of the test meter, the total uncertainty is an estimate of the maximum relative offset between the “corrected” measurement result of the power meter and the true value of the measurand, at the given confidence level

NOTE The total uncertainty includes both the uncertainty at reference conditions and the total operational uncertainty. It excludes all random uncertainties observed by the **user** of the test meter. The latter may be assessed by the user of the power meter, by making multiple measurements at the specific measurement conditions.

The term “accuracy” should be avoided in this context.

2.1.43

traceability

the property of a result of a measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of comparisons [Annex B, [1], 6.12]

NOTE Power meters calibrated and specified by the rules of this standard are traceable. In the sense of this standard, **direct** traceability of the measurement result, to either a national standards laboratory or to an accredited calibration laboratory, shall be demonstrated, which includes regular recalibration schedules of all power meters in the calibration chain, detailed calculations of all uncertainties at reference conditions and of all transfer uncertainties in the calibration chain.

If the above conditions are met, then **indirect** traceability to other national standards laboratories is provided by regular intercomparisons between the national laboratories.

2.1.44

transfer

comparison of the output of a parent meter (usually a standard) to the output of a test meter, by exposing both meters to a set of reference conditions, and transfer of the parent meter measurement result to the test meter, including necessary corrections. The latter may be performed either by an adjustment of the test meter, or by documentation of a correction factor in a calibration certificate. The transfer is part of the calibration at reference conditions

2.1.45

transfer standard

a standard used as an intermediary to compare standards or measuring instruments [Annex B, [1], 6.10]

2.1.46

(cumulative) transfer uncertainty

an estimate characterizing the additional uncertainty of a test meter caused by uncertainties in the transfer process at the given confidence level

2.1.47

transfer uncertainty of the parent meter

the (individual) uncertainty of the parent meter caused by the difference between:

- a) a single parameter of the reference conditions at which the parent meter was calibrated; and
- b) the same parameter when the parent meter is used in the comparison with the test meter. The term is also used for the uncertainty as accumulated from several of the individual transfer uncertainties of the parent meter.

NOTE Note that both individual and accumulated transfer uncertainties of the parent meter are systematic uncertainties; they should be characterized either by an uncertainty band, or by an equivalent standard deviation. Also note that the change of condition additionally should be described by a correction factor which is included in the transfer uncertainty of the parent meter.

2.1.48

transfer uncertainty of the test meter

the (individual) uncertainty of response of a test meter caused by changing one parameter of the reference conditions within its tolerance band. The term is also used for the uncertainty as accumulated from several of the individual transfer uncertainties of the test meter

NOTE Note that both individual and accumulated transfer uncertainties of test meter are systematic uncertainties; they should be characterized either by an uncertainty band, or by an equivalent standard deviation.

2.1.49

uncertainty at reference conditions

an estimate characterizing the range of relative offsets (uncertainty range) between the measurement result and the true value of the measurand, at the given confidence level, when the power meter is exposed to the reference conditions. The closest approximation to the true value of the measurand is defined by the national working standard, and the uncertainty at reference conditions **includes** the uncertainty of the national working standard

NOTE The uncertainty at reference conditions includes all uncertainties in the calibration chain (uncertainties of the power meters in the chain and cumulative transfer uncertainties), from the national working standard to the test meter.

The uncertainty at reference conditions is the uncertainty applicable when the test meter is operated at the reference conditions. It excludes all random uncertainties observed by the user of the test meter. The term “accuracy” should be avoided in this context.

2.1.50

uncertainty range

the range of uncertainties within which the true value of the measurand lies at the given confidence level

NOTE When the distribution of measurement samples is assumed to be gaussian, and the confidence level is 95 %, then the width of the uncertainty range is defined by $\pm 2 \times$ the standard deviation for a large number of measurements. When the confidence level is 99,7 %, then the width of the uncertainty range is defined by $\pm 3 \times$ the standard deviation for a large number of measurements. The uncertainty at reference conditions and the total uncertainty of a power meter should be specified in the form of uncertainty ranges.

2.1.51

working standard

a standard which, usually calibrated against a reference standard, is used routinely to calibrate or check measuring instruments [Annex B, [1], 6.09]

2.1.52

zero error

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

2.2 Mathematical basis

This standard distinguishes three types of deviations between the actual measurement result and the “true” measurement quantity: known deviations, which can be corrected; systematic uncertainties; and random uncertainties. Each of these may be caused by an individual influencing quantity, or may be accumulated from contributions caused by a number of influencing quantities. This subclause suggests a standardized form of accessing, accumulating, and reporting these contributions.

2.2.1 Deviations and correction factors

A **deviation**, Δr , quantifies the **relative** difference between the actual response of a power meter, r_{actual} , and the response of a reference power meter, r_{ref} (see Figure 1). If the two responses are approximately equal, then the deviation can also be expressed by the relative difference of power levels:

$$\Delta r = \frac{r_{\text{actual}} - r_{\text{ref}}}{r_{\text{ref}}} \approx \frac{P_{\text{actual}} - P_{\text{ref}}}{P_{\text{ref}}} \quad [\text{relative units}] \quad (1)$$

Instead of the deviation, alternatively a **correction factor** can be recorded, by which the power meter measurement result is to be multiplied in order to obtain the “true” measurement result. The correction factor can be calculated with the help of the influencing condition, for example the temperature, and the power meter dependence on a change of this condition:

$$CF = 1 - (\text{change of influencing condition} \times \text{power meter sensitivity}) \quad (2)$$

The deviation, Δr , and the correction factor, CF , are related by:

$$CF = \frac{1}{1 + \Delta r} \approx 1 - \Delta r \quad (3)$$