This mail sent on 27th April 2017 from president_cmai@cmai.asia

Subject: Voting on IEC TC /86, 86B Documents (LITD 11) Optical fibre documents

Dear Sir,

we invite your views on enclosed documents pertaining to optical fiber equipment/devices etc. for BIS within next 2 days.

REGARDS

Prof N K Goyal
President CMAI Association of India, Chairman Emeritus TEMA
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----- Forwarded Message -----
From: jambholkar.bis <jambholkar@bis.gov.in>
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Sent: Tuesday, 25 April 2017 3:47 PM
Subject: Voting on IEC TC /86, 86B Documents (LITD 11)

To,

All Members of Fibre Optics, Fibres, Cables and Devices Sectional Committee, LITD 11

Dear Madam/Sir,

Please find enclosed herewith the following document(s) of IEC Committee and Sub Committees **86 Fibre optics, 86 Fibres and cables**, and **86B: Fibre optic interconnecting devices and passive components** due for voting by the due date indicated against each document:

Sl No.	Doc./Ref. No.	Stage	Title	Due Date
1	86/511/CD	CD	Calibration of fibre-optic power meters	12/05/2017
2	86/514/CD	CD	Calibration of wavelength/optical frequency measurement instruments - Part 3:Optical frequency meters internally referenced to a frequency comb	30/06/2017
3	86B/4076/FDIS	FDIS	Fibre optic interconnecting devices and passive components - Performance standard - Part 121-2 : Simplex and duplex cords with single-mode fibre and cylindrical ferrule connectors for category C -	05/05/2017

			Controlled environment	

2. India is a Participating (P) Member on IEC/ TC 86 and Observer (O) Member of 86B the Committee responsible for preparation of this(these) document(s). As P Member of IEC/TC 86, it is our obligation to vote on these documents. We can also vote/comment on documents even if we are O-members. LITD 11 acts as the national mirror committee of TC 86, 86A and 86B. You, being member of LITD 11, are requested to kindly examine this(these) document(s) and let us have your comments in the attached format, if any, for forwarding to TC 86, 86A and 86B.

3. You, being the member of LITD 11, are requested to kindly let us know whether we should vote in favour or against the document(s) or abstain from voting. Kindly send your reply within a week and comments if any in the attached format so as to enable us to send the India’s viewpoint to IEC.

धन्यवाद/With warm regards,

बिपिन जांभोलकर/ Bipin Jambholkar

भारतीय मानक ब्यूरो/Bureau of Indian Standards

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86/511/CD

COMMITTEE DRAFT (CD)

PROJECT NUMBER: **IEC 61315 ED3**	
DATE OF CIRCULATION: **2017-01-20**	CLOSING DATE FOR COMMENTS: **2017-05-12**
SUPERSEDES DOCUMENTS: **86/492/CD,86/503A/CC**	

IEC TC 86 : FIBRE OPTICS	
SECRETARIAT: United States of America	SECRETARY: Mr Steve Swanson
OF INTEREST TO THE FOLLOWING COMMITTEES:	PROPOSED HORIZONTAL STANDARD: ☐ Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.
FUNCTIONS CONCERNED: ☐ EMC ☐ ENVIRONMENT ☐ QUALITY ASSURANCE ☐ SAFETY	

This document is still under study and subject to change. It should not be used for reference purposes.

Recipients of this document are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

TITLE:

Calibration of fibre-optic power meters

NOTE FROM TC/SC OFFICERS:

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

CALIBRATION OF FIBRE-OPTIC POWER METERS

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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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 Section 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 standard is based on the following documents:

FDIS	Report on voting
86/xxx/FDIS	86/xxx/RVD

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

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

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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 shall 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) experience-based, type B 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 5.4, 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 standard. One of these dependences, the nonlinearity, is determined in a separate calibration (Clause 7).

CALIBRATION OF FIBRE-OPTIC POWER METERS

1 Scope

This international standard 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. 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 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 60359:2001, *Electrical and electronic measurement equipment – Expression of performance*

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

IEC TR 61931, *Fibre optic – Terminology*

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

VIM: JCGM 200:2012, *International vocabulary of metrology – Basic and general concepts and associated terms*

GUM: JCGM 100:2008, *Evaluation of measurement data – Guide to the expression of uncertainty in measurement*

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 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.

[IEV 311-03-16; see also VIM 3.11, modified]

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

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.

[See also VIM 2.39, modified]

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:

$$\lambda_{\mathrm{c}} = \frac{\int p(\lambda)\lambda d\lambda}{P_{\mathrm{total}}} \quad (1)$$

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

$$\lambda_{\mathrm{c}} = \frac{\sum_{i} P_{\mathrm{i}}\lambda_{\mathrm{i}}}{\sum_{i} P_{\mathrm{i}}} \quad (2)$$

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

[See also VIM]

3.7
detector

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

[SOURCE: IEC 61931; see also VIM, 3.9, modified]

3.8
deviation

D

for the purposes of this standard, the relative difference between the power measured by the test meter (3.32) P_{DUT} and the reference power P_{ref}

$$D = \frac{P_{\mathrm{DUT}} - P_{\mathrm{ref}}}{P_{\mathrm{ref}}} \qquad (3)$$

3.9
excitation (fibre)

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 (3.31) on the surface of the fibre end, and

b) 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 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:

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

[SOURCE: IEC TR 61931, definition 2.1.15, mainly modified by adding the equation]

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 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.

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 to entry: 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.

[See also VIM 4.7, modified]

3.14

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

[See also VIM 5.3, modified]

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:

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

If expressed in decibels, the nonlinearity is:

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

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. In this standard, the numerical aperture is the sine of the (linear) half-angle at which the irradiance is 5 % of the maximum irradiance.

[SOURCE: IEC 60793-1-43, modified – adapted 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]

3.18

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 to entry: The operating conditions and uncertainty at operating conditions are usually specified by 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. 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.

3.21

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 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

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

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

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

3.23

power meter (fibre-optic)

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

Note 1 to entry: 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 shall be calibrated together with the main instrument.

Note 2 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 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 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 there are derived

[See also VIM 5.6, modified]

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:

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

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

3.29
(spectral) responsivity

R

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

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

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

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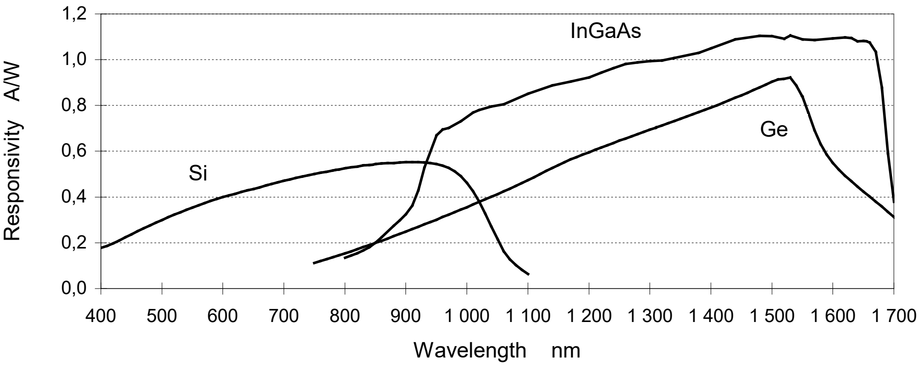
[1] Figures in square brackets refer to the Bibliography.



IEC 1826/05

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).

$$B = 2{,}35\sqrt{\frac{1}{P_{\mathrm{total}}}\sum_i P_{\mathrm{i}}(\lambda_i - \lambda_{\mathrm{c}})^2} \qquad (10)$$

$$P_{\mathrm{total}} = \sum_i P_{\mathrm{i}} \qquad (11)$$

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 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.

3.31
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 (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, it shall be stated with the spot diameter value.

3.32

test meter

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

[See also VIM 2.41, modified]

3.34

traceability chain

unbroken chain of comparison

[See also VIM 2.42, modified]

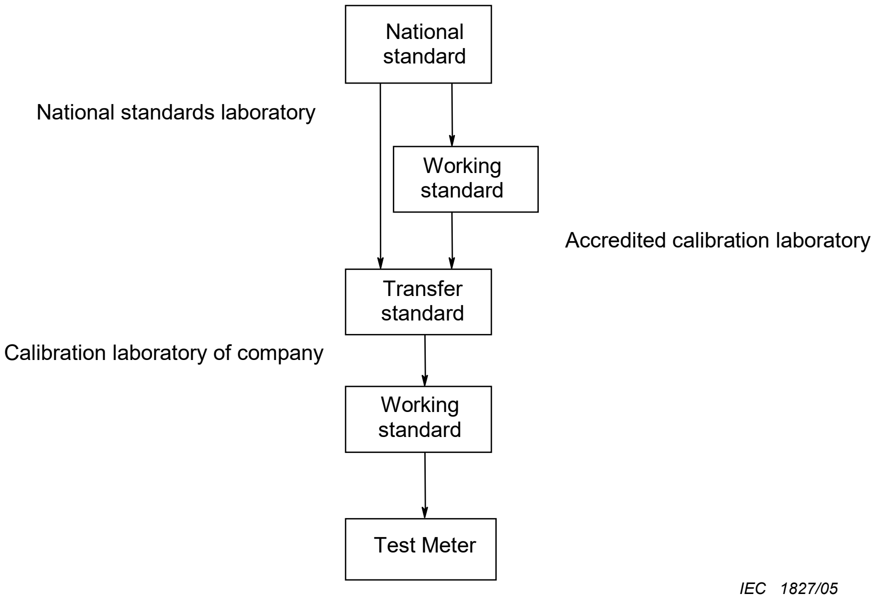


Figure 2 – Example of a traceability chain

3.35

working standard

standard that is used routinely to calibrate or check measuring instruments

[See also VIM 5.7, modified]

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

3.36

zero error

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

[See also VIM 4.28, modified]

4 Preparation for calibration

4.1 Organization

The calibration laboratory should satisfy requirements of ISO/IEC 17025.

There should be a documented measurement procedure for each type of calibration performed, giving step-by-step operating instructions and equipment to be used.

4.2 Traceability

The requirements of ISO/IEC 17025 should be met.

All standards used in the calibration process shall be calibrated according to a documented program with *traceability* to *national standards laboratories* or to *accredited calibration laboratories*. It is advisable to maintain more than one standard on each hierarchical level, so that the performance of the standard can be verified by comparisons on the same level. Make sure that any other test equipment which has a significant influence on the calibration results is calibrated. Upon request, specify this test equipment and its *traceability chain*(s). The re-calibration period(s) shall be defined and documented.

4.3 Advice for measurements and calibrations

This subclause gives general advice for all measurements and calibrations of optical and fibre-optic power meters.

The calibration should be made in a temperature-controlled room if non-temperature-controlled detectors are used. The recommended temperature is 23 °C. Humidity control may be necessary if humidity-sensitive optical detectors are used, or if there is the possibility of condensation on the components. A change of the laboratory's humidity may change the absorption of air and thereby change the power. This effect is relatively strong between 1 360 nm and 1 410 nm, especially when a sequential-type, open-beam calibration is used and the humidity changes between the steps. In parallel-type calibrations with open-beam paths of approximately the same lengths, the measurement results of both the reference meter and the test meter will change at approximately the same time, with negligible effect on the calibration result.

The laboratory should be kept clean. Connectors and optical input ports should always be cleaned before measurement. The quality and cleanness of the connector in front of the detector should be checked. All fibres should be moved as little as possible during the measurements; they can be fixed to the workbench if necessary. Sensors should be moved to the fibre rather than the fibre to the sensor.

The optical source that is used for the excitation of the power meter should be characterized for centroidal wavelength and spectral bandwidth. The spectral bandwidth should be narrow enough to avoid averaging over a wide range of wavelengths. Means to ensure the stability of the source, for example with the help of independent power monitoring, may be advisable.

Laser diodes are sensitive to back reflections. To improve the stability, it is advisable to use an optical attenuator or an optical isolator between the laser diode and the test meter. Because of their narrow spectral bandwidths, the combination of laser diode and multimode fibre is also capable of producing speckle patterns on the optical reference plane, with the result of an increased measurement uncertainty.

Fibre connectors and connector adapters are likely to produce errors in the measurement result [2] because of multiple reflections between the *optical input port* (or detector) and the connector-adapter combination (as part of the source). Therefore, connectors and adapters with low reflectivity are recommended for the calibration. Otherwise, a correction factor and an increased uncertainty may have to be taken into account.

It is advisable to use reference meters with detector diameters of ≥ 3 mm, because they can easily be irradiated with an open beam, and they are less susceptible to contamination (dirt and dust). The reference meter's surface reflections should be as small as possible. If the source emits a divergent beam, then a reference meter with an integrating sphere may be advisable. It is also acceptable to use meters with "flat" detectors and mathematical correction, based on multiplying the emitted far field distribution with the measured angle-dependence of the detector of the reference meter, and integrating over the range of far-field angles.

Temperature control of the detectors should be considered for highly accurate calibrations, because detectors exhibit strong temperature dependence over some wavelength ranges.

4.4 Recommendations to users

It is recommended that the user of the power meter maintain at least one reference power meter, which allows comparison of the meters for confidence. These comparisons are particularly important before and after the meter is sent to re-calibration, because they will allow the user to determine whether or not his scale has changed – for example due to transport – after the meter returns. Scale changes due to adjustment (3.2) (see IEV 311-03-16 and VIM 4.30) will be reported on the calibration certificate.

A regular comparison of the correction factors (3.6), or of the deviations (3.8), will allow the user to screen out excessive ageing, and possibly to adjust the recalibration intervals.

5 Absolute power calibration

5.1 Calibration methods

The calibration of a power meter is usually achieved by exposing both the meter under test and a calibrated power meter with known uncertainty (the reference meter) to an optical radiation, and by transferring the reference meter's (3.26) measurement result to the test meter (3.32).

The allowable spectral bandwidth (3.30) depends on the test meter's spectral responsivity (3.29); the stronger its wavelength dependence, the narrower the spectral bandwidth. Usual bandwidths are ≤10 nm, which excludes the possibility of calibrating with wider-bandwidth LEDs. Therefore, either combinations of "white-light" sources and narrow-bandwidth filters (for example monochromators), laser diodes or combinations of supercontinuum lasers with tuneable bandpass filters are used in fibre-optic power meter calibrations.

Depending on the type of source and the exciting beam geometry, six most frequent calibration methods can be distinguished:

Table 1 –Calibration methods and correspondent typical power

Radiation source	Open-beam calibration	Fibre beam calibration
"White-light" with filter	$P \approx 10$ µW	$P \approx 10$ nW to 0,3 µW (MMF) $P \approx 2$ nW (SMF)
Laser diode	$P \approx 10$ µW to a few mW	$P \approx 10$ µW to a few mW (SMF and MMF)
Supercontinuum laser with filter	$P \approx 1$ µW to a few mW	$P \approx 1$ µW to 700 µW (SMF and MMF)
MMF: multimode fibre (usually graded-index fibre) SMF: single-mode fibre		

For fibre-optic power meters, fibre beam calibration is recommended. For open-beam calibration, a correction of the calibration results using a series of fibre beam laser calibration results at a few wavelengths should be performed.

One can distinguish between the sequential and the parallel measurement method. When reference meter and test meter are sequentially exposed to the source, then the radiated power should be kept as constant as possible, for example by appropriate stabilization. For the parallel-type calibration, a beam splitter or a branching device is used to generate two beams that excite both the reference meter and the test meter simultaneously. In this case, the beam splitter or branching device ratio shall be determined as accurately as possible, and its stability shall be investigated.

As an example, a measurement setup for sequential, fibre-based calibration is illustrated in Figure 3. A launching device, for removal of the cladding modes and creation of an appropriate modal excitation, is included in the setup.

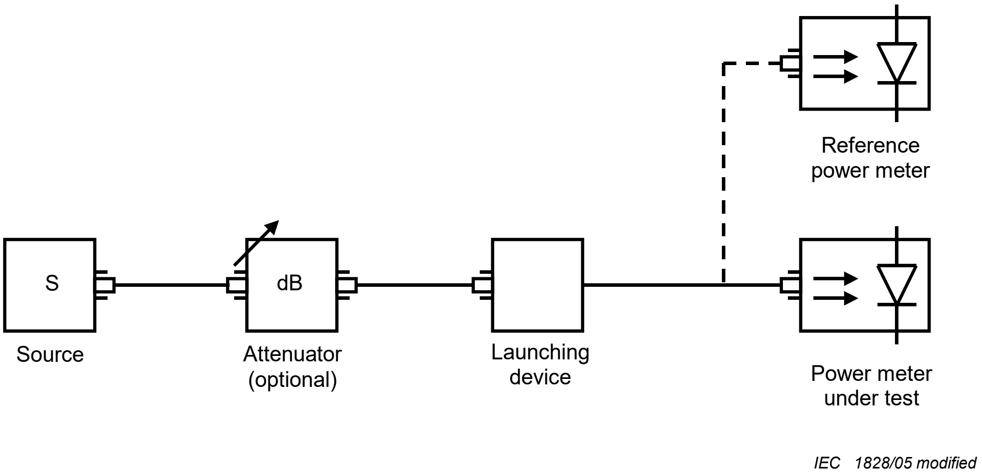


Figure 3 – Measurement setup for sequential, fibre-based calibration

5.2 Establishing the calibration conditions

The calibration conditions (3.4) are the measurement conditions during the calibration process. Establishing and maintaining the calibration conditions is an important part of the calibration (3.3), because any change of these conditions is capable of producing erroneous measurement results. The calibration conditions should be a close approximation to the intended operating conditions (3.18). This ensures that the (additional) uncertainty in the operating environment is as small as possible. The calibration conditions should be specified in the form of nominal values with uncertainties when applicable. In order to meet the requirements of this standard, the calibration conditions shall at least consist of:

a) the date of calibration;

b) the ambient temperature with uncertainty, for example 23 °C ± 1 °C;

c) the ambient relative humidity, if it has an influence, otherwise a relative humidity below the condensation point is assumed;

d) the nominal radiant power on the optical reference plane (3.21);

e) the beam geometry:

   1) an open (for example collimated) beam, described by the spot diameter (3.31) on the optical reference plane, the beam's numerical aperture (3.17) and the irradiance (3.11) distribution in the beam. Typical irradiance distributions are: uniform, Gaussian or even irregular (speckled);

   2) the type of fibre and, if applicable, its degree of excitation (for example within encircled flux templates defined in IEC 61280-4-1 when using an A1a or A1b multimode fibre);

f) the connector-adapter combination: the connector type, polishing and adapter as part of the exciting source (if applicable);

g) the centroidal wavelength (3.5) of the exciting source with its uncertainty;

h) the spectral bandwidth (3.30) of the exciting source with its uncertainty;

i) the state of polarization: "unpolarized light" or "polarized light, undefinite state". If the latter is chosen, the uncertainty due to polarization dependent response (3.22) shall be taken into account in 5.4.2 and 5.4.4.

The above conditions may not be exhaustive. There may be other parameters that have a significant influence on the calibration uncertainty and therefore shall be reported, too.

In the calibration with an **open-beam**, the power meter's *optical reference plane* (3.21) should be centrally irradiated with a beam diameter smaller than the active area of the optical reference plane.

In the calibration with a fibre, a single-mode fibre or a multimode fibre may be used. A single-mode fibre may be advantageous because of its reproducible beam characteristics, but may not be available for all wavelengths. If a multimode fibre is used, then excitation between 85 % and 95 % (slightly underfilled) is preferred because this excitation can be more easily reproduced (encircled flux templates defined in IEC 61280-4-1 are a good example of this condition). A launching device may be necessary to create the appropriate excitation. Note that multimode fibres will emit irregular beam patterns (speckle patterns) when driven by a laser diode; this will result in an increased calibration uncertainty.

A connector-adapter combination should only be reported if the power meter is calibrated with a fibre, not with an open beam. It is recommended to use a combination of connector and adapter with sufficiently low reflections back to the power meter.

5.3 Calibration procedure

(1) Establish and record the appropriate calibration conditions (5.2). Switch on all instrumentation and wait for enough time to stabilize.

(2) Set up the instrument state (3.10) of the reference meter and test meter according to the instruction manual. Set the wavelength on all instruments for the source wavelength. Select appropriate power ranges. Record the instrument states of both meters. Adjust the zero of both meters if applicable.

(3) Measure the optical power with the reference meter $P_{\text{std},1}$. Multiply the measurement result by the correction factor of the reference meter CF_{std} reported in its calibration certificate if it has not been adjusted. Multiply by the correction factor CF_{change} calculated in 5.4.3 if necessary. Record the measurement result, $P_{\text{ref},1} = P_{\text{std},1}$ x CF_{std} x CF_{change}.

(4) Measure the optical power with the test meter. Apply necessary corrections as suggested by the operating instructions. Record the measurement result, $P_{\text{DUT},1}$.

(5) Calculate the first of a series of correction factors:

$$CF_{\text{comparison},1} = \frac{P_{\text{ref},1}}{P_{\text{DUT},1}} \tag{12}$$

(6) Repeat steps (3) through (5) several times, with the result of obtaining several correction factors, $CF_{\text{comparison},1}$ to $CF_{\text{comparison},n}$.

(7) Calculate and record the average correction factor, CF_{DUT} from the individual correction factors:

$$CF_{\text{DUT}} = \frac{1}{n} \cdot \sum_{i=1}^{n} CF_{\text{comparison},\,\text{i}} \tag{13}$$

If desired the deviation D can be calculated from the correction factor:

$$D = \frac{1}{CF_{\mathrm{DUT}}} - 1 \qquad (14)$$

In later use of the test meter, the measurement results shall be multiplied with CF_{DUT}. Alternatively, an adjustment (3.2) of the test meter can be made so that the correction factor is changed to 1. In this case, the comparison should be repeated for verification.

5.4 Calibration uncertainty

The calibration uncertainty is the measurement uncertainty of the correction factor CF_{DUT}. Calculate the combined standard uncertainty from:

$$u(CF_{\mathrm{DUT}}) = \sqrt{u_{\mathrm{setup}}^2 + u_{\mathrm{ref}}^2 + u_{\mathrm{DUT}}^2} \qquad (15)$$

where

u_{setup} = uncertainty due to the setup, (5.4.1);

u_{ref} = uncertainty of the reference meter, (5.4.2);

u_{DUT} = uncertainty due to the test meter, (5.4.4).

NOTE Equation (15) is valid only if the input quantities are independent or uncorrelated. If some input quantities are significantly correlated, take the correlation into account. See GUM for more detail.

Then calculate the expanded uncertainty from:

$$U(CF_{\mathrm{DUT}}) = k \times u(CF_{\mathrm{DUT}}) \qquad (16)$$

where k is the coverage factor. See Annex A for more detail.

5.4.1 Uncertainty due to the setup

The following uncertainties may come from the setup:

a) Uncertainty due to the source power instability. In addition to the intrinsic variation of output power versus time, a laser source may react with unstable power to variations of back-reflections and variations of the state of polarisation of back-reflected light.

b) Uncertainty due to the beam splitter or branching device ratio (for parallel method), for example due to their polarization dependence.

c) Depending on the setup and method, other uncertainties may have to be taken into account.

Instability of the source power, of the beam splitter or branching device ratio (for parallel method) will cause a scatter in the measurement of the correction factor. The uncertainty due to these instabilities can be calculated from the experimental standard deviation of the correction factors $CF_{\mathrm{comparison,1}}$ to $CF_{\mathrm{comparison,n}}$ measured during the calibration (Equation (12)). The number of comparisons should be large to reduce this uncertainty. See Annex A for more detail on type A evaluation of uncertainty.

$$u_{\mathrm{setup,typeA}} = \frac{s(CF_{\mathrm{comparison}})}{\sqrt{n}} \qquad (17)$$

where:

$s(CF_{\mathrm{comparison}})$ is the experimental standard deviation of the correction factors;

n is the number of measurement cycles during the calibration process.

This uncertainty can also be calculated from a standard deviation evaluated once from measurements and used for all calibrations or from a type B evaluation. The instability should therefore not vary too much from one calibration to the next and not depend on the test meter. The number n in Equation (17) is always the number of measurement cycles during the current calibration process.

This type A evaluated uncertainty will also be influenced by the repeatability of the connection when using a sequential measurement method or by slight changes in the measurement conditions during the calibration process. It can (partially) take into account some of the uncertainties due to the reference meter (5.4.2) or test meter (5.4.4). Uncertainty components should not be taken twice into account but also not be forgotten.

Calculate the uncertainty due to the setup by combining all partial uncertainties described in this subclause:

$$u_{\text{setup}} = \sqrt{\sum_{i=1}^{m} u_{\text{setup,i}}^{2}} \tag{18}$$

5.4.2 Uncertainty of the reference meter

The uncertainty of the reference meter is mainly due to its calibration, to the uncertainties of the current calibration conditions (3.4) and to the dependence of the reference meter on these conditions.

The following uncertainties shall be evaluated. The evaluation can be made on the basis of measurements or estimations, or a mixture of both. The calculation of uncertainties is described in Annex A. The measurement of dependence on conditions is described in 6.3.1.

a) Calibration uncertainty of the reference meter. It shall be obtained from its calibration certificate;

b) Uncertainty due to the change from the conditions in which the reference meter was calibrated and the current calibration conditions u_{change} as calculated in 5.4.3;

c) Uncertainty due to temperature dependence of the reference meter;

d) Uncertainty due to dependence on relative humidity of the reference meter. Power meters with integrating sphere are particularly sensitive to absorption peaks of water when using narrow laser sources;

e) Uncertainty due to dependence on the beam geometry of the reference meter;

f) Uncertainty due to dependence on multiple reflections. Multiple reflections may exist between the optical input port and the radiation source (for example a connector-adapter combination). Different artefacts will change the measured power;

g) Uncertainty due to wavelength dependence of the reference meter;

h) Uncertainty due to dependence on source spectral bandwidth of the reference meter;

i) Uncertainty due to dependence on state of polarization of the reference meter, except if unpolarized or depolarized light is used for calibration;

j) Uncertainty due to optical interference. Fabry-Perot cavities can occur between the surface of the detector, of the window and the end of the connector, if used;

k) Uncertainty due to the resolution of the reference meter. If the resolution of the reference meter is δy_{ref}, the standard uncertainty is (see GUM, F.2.2.1):

$$u_{\text{ref,resolution}} = \frac{1}{2\sqrt{3}}\,\delta y_{\text{ref}} \tag{19}$$

l) Uncertainties due to other dependences of the reference meter. Depending on the type of reference meter, there may be other uncertainties of the reference meter. These should also be measured or estimated;

m) Uncertainty due to ageing of the reference meter.

Then calculate the combined standard uncertainty of the reference meter from the n above standard uncertainties:

$$u_{\mathrm{ref}} = \sqrt{\sum_{i=1}^{n} u_{\mathrm{ref,i}}^2 + u_{\mathrm{change}}^2} \tag{20}$$

where u_{change} is the uncertainty due to the change of conditions, as determined from 5.4.3.

5.4.3 Correction factors and uncertainty caused by the change of conditions

The reference meter may exhibit a different response because it was calibrated under conditions different from the current calibration conditions. Examples for differences between the two sets of measurement conditions are: Parallel beam versus divergent beam, different source spectra, a non-reflecting setup versus a setup with multiple reflections, or a large time span between the two reference dates resulting in ageing of the standard.

If the conditions under which the reference meter was calibrated are nominally identical to the current calibration conditions (their uncertainties can be different) and if the ageing of the reference meter is negligible, this clause can be skipped (CF_{change} = 1).

As indicated in Figure 4, each change comprises the nominal change of condition and the change of uncertainty.

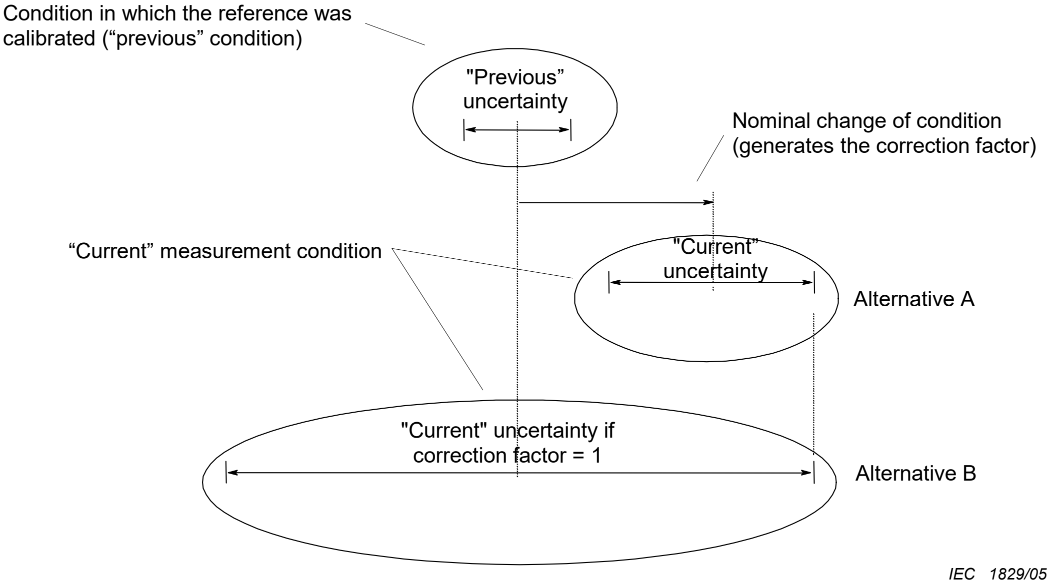


Figure 4 – Change of conditions and uncertainty

For each of the potential error contributions (5.4.3.1 to 5.4.3.7) one should decide if it is sensible to calculate a correction factor or not. **Alternative A** includes the calculation of a correction factor with the result of a relatively small uncertainty. **Alternative B** means waiving the correction factors (or CF_{change} = 1) and taking larger uncertainties into account to embrace the worst-case conditions.

If the alternative A is chosen, the (cumulative) correction factor is:

$$CF_{\text{change}} = \frac{r_{\text{previous}}}{r_{\text{current}}} \tag{21}$$

or

$$CF_{\text{change}} = 1 - \Delta r \tag{22}$$

where

r_{previous}	is the response of the reference with excitation at the conditions at which it was calibrated;
r_{current}	is the response of the reference with excitation at the current calibration conditions;
Δr	is the relative change of response $\Delta r = (r_{\text{current}} - r_{\text{previous}}) / r_{\text{current}}$.

Calculate the (cumulative) reference meter's change-related correction factor by accumulating the partial correction factors, $CF_{\text{change,i}}$, outlined in 5.4.3.1 to 5.4.3.7. For each influencing quantity X_{i}, start with the calculation of the partial correction factor:

$$CF_{\text{change,i}} = 1 - \Delta r_{\text{i}} \tag{23}$$

The relative change of response Δr_{i} can be directly measured by changing the influencing quantity from the “previous” to the “current” calibration conditions or calculated from the nominal change of the influencing quantity Δx_{i}, and the reference meter's nominal relative dependence on this quantity:

$$CF_{\text{change,i}} = 1 - c_{\text{i}} \times \Delta x_{\text{i}} \tag{24}$$

where c_{i} is the partial derivate of the relative response on the influence quantity X_{i}, called **sensitivity coefficient**. See GUM (5.1.3 and 5.1.4) for more detail.

If the sensitivity coefficient is not known very well, the following type B uncertainty should be taken into account:

$$u_{\text{change,i}} = u(c_{\text{i}}) \times \Delta x_{\text{i}} \tag{25}$$

where $u(c_{\text{i}})$ is the standard uncertainty of the sensitivity coefficient. The measurement of the dependences is discussed in 6.3.

Finally, calculate the reference meter's cumulative correction factor from the above contributions:

$$CF_{\text{change}} = \prod_{i=1}^{n} CF_{\text{change, i}} \tag{26}$$

and the combined standard uncertainty due to the change of calibration conditions:

$$u_{\text{change}} = \sqrt{\sum_{i=1}^{n} u_{\text{change,i}}^{2}} \tag{27}$$

This correction factor corresponds to a **known** change of response of the reference meter caused by the two different sets of measurement conditions. It is a correction factor to apply to the power read by the reference meter (see 5.3).

5.4.3.1 Correction factor due to temperature change

The correction factor $CF_{\text{change},\Theta}$ should be calculated with the help of the nominal change between the "previous" and the "current" temperature $\Delta\Theta$ and the temperature sensitivity coefficient c_{Θ} of the reference meter (for example in %/°C).

$$CF_{\text{change},\Theta} = 1 - c_{\Theta} \times \Delta\Theta \tag{28}$$

5.4.3.2 Correction factor due to change of power level

The uncertainty should be calculated from the nonlinearity of the reference meter between the "previous" and the "current" power level. If necessary, a correction factor can be calculated from:

$$CF_{\text{change,NL}} = 10^{\frac{-NL}{10}} \tag{29}$$

where NL is the nonlinearity, expressed in decibels (dB). Measurement of nonlinearity is described in Clause 7.

5.4.3.3 Correction factor due to change of beam geometry

The correction factor should be calculated from the change of response measured when changing the beam geometry.

5.4.3.4 Correction factor due to dependence on multiple reflections

The reference meter's optical input port should generally be assumed to be reflective. Such a reflection will travel back to the radiation source, be reflected again, and finally increase the displayed optical power level. This effect will give rise to a correction factor (usually < 1) and an increased uncertainty.

If, for example, the source used in the calibration of the reference meter was non-reflective and the source used in the calibration of the test meter is reflective (caused by an optical connector), then the total power indicated by the reference meter is erroneous by the secondary reflection. If one assumes that the secondary reflection contributes an additional 5 % of the total power, then the individual correction factor is 0,95. This type of error can be reduced by using sources with highly absorptive enclosures, respectively sources with low-reflectivity connector-adapter combinations.

5.4.3.5 Correction factor due to wavelength change

The correction factor should be calculated with the help of the nominal change of wavelength $\Delta\lambda$ and the reference meter's nominal wavelength dependence c_{λ}.

$$CF_{\text{change},\lambda} = 1 - c_{\lambda} \times \Delta\lambda \tag{30}$$

5.4.3.6 Correction factor due to spectral bandwidth change

The correction factor should be calculated with the help of the nominal change of spectral bandwidth and the reference meter's nominal dependence on the spectral bandwidth. Note that the correction factor remains 1 as long as the (uncorrected) wavelength-dependence is **linear** within the spectral bandwidth of the source. In the case that the wavelength dependence is curved, the correction factor can be computed with the help of the wavelength-dependence of the reference meter and the spectra of the two sources used in the calibration of the reference meter and in the calibration of the test meter.

5.4.3.7 Other correction factors

Depending on the type of reference meter and the calibration conditions, there may be other correction factors. These should also be measured or estimated as outlined above.

5.4.4 Uncertainty due to the test meter

Uncertainties arising from the test meter are mainly due to the uncertainties of the calibration conditions and the dependence of the test meter on the conditions. The following uncertainties shall be evaluated. Their determination is similar to 5.4.2. The calculation of uncertainties is described in Annex A, the measurement of dependence on conditions is described in 6.3.1.

a) Uncertainty due to temperature dependence of the test meter

b) Uncertainty due to dependence on relative humidity of the test meter. Power meters with integrating sphere are particularly sensitive to absorption peaks of water when using narrow laser sources.

c) Uncertainty due to dependence on beam geometry. This uncertainty comes from non-uniformity and angle-dependence of the test meter's optical input port.

d) Uncertainty due to dependence on multiple reflections. Multiple reflections may exist between the optical input port and the radiation source (for example a connector-adapter combination). Different artefacts will change the measured power.

e) Uncertainty due to wavelength dependence of the test meter

f) Uncertainty due to dependence on source spectral bandwidth of the test meter

g) Uncertainty due to dependence on state of polarization of the test meter, except if unpolarized or depolarized light is used for calibration

h) Uncertainty due to optical interference. Fabry-Perot cavities can occur between the surface of the detector, of the window and the end of the connector, if used

i) Uncertainty due to the resolution of the test meter. If the resolution of the test meter is δy_{DUT}, the standard uncertainty is (see GUM, F.2.2.1):

$$u_{\mathrm{DUT,resolution}} = \frac{1}{2\sqrt{3}} \delta y_{\mathrm{DUT}} \tag{31}$$

j) Uncertainties due to other dependences of the test meter. Depending on the type of test meter and on the calibration process, there may be other conditions causing uncertainties.

Then calculate the combined standard uncertainty contribution of the test meter from the n above standard uncertainties:

$$u_{\mathrm{DUT}} = \sqrt{\sum_{i=1}^{n} u_{\mathrm{DUT,i}}^{2}} \tag{32}$$

5.5 Reporting the results

The results of each calibration should be reported as required by ISO/IEC 17025. Calibration certificates or calibration reports referring to this standard shall at least include the following information:

a) all calibration conditions (3.4) as described in 5.2;
b) the test meter's correction factor(s) (3.6) or deviation(s) (3.8), if the test meter was not adjusted;
c) on receipt correction factors or deviations and after adjustment (3.2) correction factors or deviations in the case that an adjustment was carried out;
d) the calibration uncertainty in the form of an expanded uncertainty as described in 5.4;
e) the instrument state (3.10) of the test meter during the calibration;
f) evidence that the measurements are traceable (see ISO/IEC 17025:2005, 5.10.4.1 c)).

6 Measurement uncertainty of a calibrated power meter

6.1 Overview

The measurement uncertainty of a calibrated power meter is larger than its calibration uncertainty. It is the combination of the calibration uncertainty and of uncertainty contributions due to the dependence of the power meter on the conditions of measurement.

The determination of the measurement uncertainty of a calibrated power meter used at reference conditions or at operating conditions is not part of the calibration process. It is performed for example by manufacturers of power meters in order to establish specifications. It is not mandatory for calibration certificates or calibration reports referring to this standard.

6.2 Uncertainty at reference conditions

Reference conditions (3.25) are used for testing the performance of a power meter or for intercomparisons. They are usually defined by manufacturers in order to specify the smallest uncertainty of a measuring instrument; therefore, they are often identical or close to its calibration conditions.

The uncertainty at reference conditions is the uncertainty on the result of a measurement taken by the calibrated and adjusted power meter when operated at reference conditions. It depends on the calibration uncertainty of the power meter, the reference conditions and the dependence of the power meter on the reference conditions. This is the reason why the uncertainty at reference conditions is always larger than the calibration uncertainty. Even when the reference conditions are identical with the calibration conditions (no uncertainty due to change of conditions), the test (power) meter’s dependences on the reference conditions have to be added (in quadrature) to the calibration uncertainty for a second time. Calculating the uncertainty at reference conditions of the calibrated test meter is similar to calculating the measurement uncertainty at calibration conditions of the reference meter described in 5.4.2:

$$u_{\mathrm{DUT,ref\_conditions}} = \sqrt{u^2(CF_{\mathrm{DUT}}) + u_{\mathrm{DUT}}^2} \tag{33}$$

where

$u(CF_{\mathrm{DUT}})$ is the calibration uncertainty of the test meter, as determined from 5.4, and

u_{DUT} is the uncertainty due to the dependence of the test meter on the reference conditions, as determined from 5.4.4.

The description of the reference conditions should be made in the same way as the calibration conditions described in 5.2.

6.3 Uncertainty at operating conditions

The uncertainty at operating conditions (or operating uncertainty, see 2.2.11 of IEC 60359) is the uncertainty on the result of a measurement taken by the calibrated and adjusted power meter when operated within a range of operating conditions (3.18). It depends on the calibration uncertainty, the operating conditions and the dependence of the power meter on the operating conditions:

$$u_{\mathrm{DUT,operating}} = \sqrt{u^2(CF_{\mathrm{DUT}}) + u^2_{\mathrm{extension}}} \tag{34}$$

where

$u(CF_{\mathrm{DUT}})$	is the calibration uncertainty of the test meter, as determined from 5.4, and
$u_{\mathrm{extension}}$	is the extension uncertainty, due to the dependence of the meter on the operating conditions, as determined from Equation (38).

Contrary to the *calibration conditions* (3.4) described in 5.2, each operating condition should be described by a range when possible. The set of operating conditions are specified by:

a) the maximum time span between recalibrations;
b) the range of ambient temperatures;
c) the range of power levels (measuring range);
d) the range of beam geometries described by their spot diameter and numerical aperture, or the range of fibre types;
e) the applicable connector-adapter combinations, if any;
f) the range of wavelengths of the source;
g) the maximum spectral bandwidth of the source.

All possible polarization states are included in the operating conditions by default. A relative humidity below the condensation point is also assumed.

The above conditions may be defined either by the power meter manufacturer or by the calibration laboratory in charge of the calibration for operating conditions.

To calculate the extension uncertainty, combine all uncertainties due to the dependences on the conditions:

$$u_{\mathrm{extension}} = \sqrt{\sum_{i=1}^{n} u^2_{\mathrm{extension,i}}} \tag{35}$$

where:

$u_{\mathrm{extension,i}}$	are contributions to the extension uncertainty;
n	is the total number of contributions.

6.3.1 Determination of dependences on conditions

Each dependence should be recorded as relative change of the meter's response, caused by changing the relevant condition within its *operating range*. During the test, all other conditions should be kept at the *calibration conditions*. The zero point is defined by the response at calibration conditions. This way, each dependence can be specified by a range that is defined by the maximum positive and negative changes of the response. An asymmetric range about the zero-point is the usual result as shown in Figure 5.

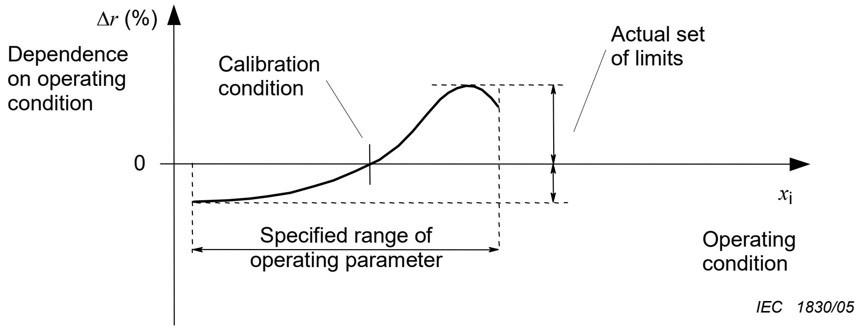


Figure 5 – Determining and recording an extension uncertainty

In order to obtain good measurement accuracy, the guidelines in Clause 4 should be observed. Uncertainties in the measurements should be as small as possible, because the measurement results shall include these uncertainties. It is acceptable to use estimations, instead of measurements, if these estimations are based on known physical relations or on a sufficiently large number of characterizing measurements of the same type of test meter.

For the determination of the combined standard uncertainty of the test meter at operating conditions, the limits quantifying the individual dependences shall be converted to standard uncertainties using Equation (A.5).

The individual uncertainties are usually assumed to be independent. However, in some instances an uncertainty may be strongly dependent on more than one condition. Examples are outlined in 6.3.4, 6.3.6 and 6.3.7. If the extension uncertainty is substantially increased by changing the other conditions (within their specified *operating ranges),* this larger uncertainty shall be recorded. The calculation of the uncertainty shall then be based on these larger uncertainties.

6.3.2 Ageing

Ageing is the relative change of response during a period. It can be determined from the results of successive calibrations of the meter at the same conditions or from indications of the manufacturer.

For a manufacturer, the relative change of response during a period shall be determined with the assumption of careful use of the instrument. It is recommended to expose the power meter to its typical environmental conditions, for example ambient temperature (23 ± 1) °C for a laboratory-type instrument, optical input port non-irradiated, continuously repetitive cycles of power-on 12 hours, power-off 12 hours, with a total test time equal to the period. The change of response should be measured by comparison with a working standard. Regular and traceable recalibration of the working standard will be necessary, in order to exclude ageing of the working standard. As always, the measurement uncertainty, in this case mostly the uncertainty of the working standard, shall be taken into account.

It is recommended to calculate the ageing uncertainty from a rectangular distribution obtained as described above (see Clause A.3). If, for example, a detector is known to increase its response by a maximum of 0,1 % per year at a certain wavelength, then the ageing uncertainty is characterized by a rectangle that extends from 0 % (at time 0) to +0,1 % (at time 1 year).

6.3.3 Dependence on temperature

The relative change of response against the response at the calibration conditions should be measured by changing the temperature within the operating temperature range. The rectangular uncertainty distribution is then defined by the most negative and the most positive relative changes of the response. Only the extremes of the response as function of the temperature are relevant, not the responses at the extremes of the temperature (see Figure 5).

Note that the temperature dependence of the spectral responsivity of semiconductor detectors depends on the wavelength.

6.3.4 Dependence on the power level (nonlinearity)

The relative change of response against the response at the calibration power level should be measured following Clause 7.

6.3.5 Dependence on the type of fibre or on the beam geometry

Fibre-optic power meters may be designed to accept fibres or open beams. It is assumed that the response of the power meter depends on the geometry of the light beam because, for example, of non-uniformity and angle-dependence of the meter's optical input port.

The relative change of response should be **measured** with a working standard that exhibits:

– negligible angle-dependence,

– negligible surface reflections, and

– a sufficiently large active area to capture the fibre beams or the open beams.

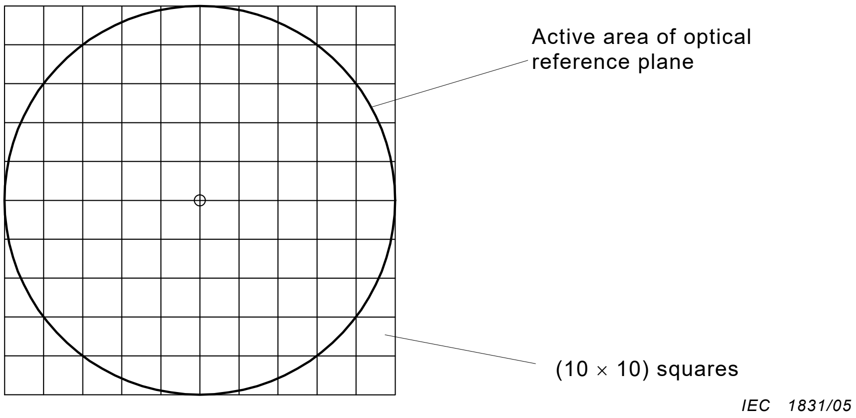


Figure 6 – Possible subdivision of the optical reference plane into 10 x 10 squares, for the measurement of the spatial response

Another possibility is evaluating the uncertainties with a **mathematical** analysis, based on the assumption that all uncertainties are caused by non-uniform spatial responses of the test meter's reference plane. In preparation of this, the active area of the optical reference plane should be subdivided into an array of squares, for example, 10 x 10 squares as in Figure 6.

Then two types of measurements should be carried out:

a) measurements of the spatial power density, together with the angles of incidence, on the optical reference plane as generated by the applicable beam geometries;

b) measurements of the test meter's spatial response, weighted with appropriate multipliers which characterize the meter's dependence on oblique incidence (angle dependence), on the test meter's reference plane. The spatial response should be measured with a beam diameter equal to the length of the square.

The change of response upon changing the beam parameters can then be evaluated on the basis of **modelling** the necessary measurement results, by multiplying the (spatial) power levels with the spatial responses and adding all products. Note that the spatial responses are usually wavelength-dependent.

6.3.5.1 Measurement of the fibre dependence

In the test of fibre-related uncertainties, multimode fibres under test should be slightly underfilled (see 5.2). The fibres should be terminated by the connector-adapter combination defined by the calibration conditions. Both the connector and the adapter should exhibit a low reflectivity, so that multiple reflections between the connector-adapter combination and the detector do not influence the measurement results. The spectral bandwidth of the source should be narrow enough to avoid averaging over a wide range of wavelengths.

Step 1: the output of the reference fibre is measured with both the working standard and the test meter, and the difference is (mathematically) adjusted to zero.

Step 2: the above procedure is applied to:

a) a standard single-mode fibre as defined by IEC 60793-2, and
b) the (specified) fibre with the largest core diameter, the fibre with the largest numerical aperture or both.

The intention of the test is to measure the dependence of the test meter on the type of fibre and on the mode volume. The largest relative change of response against step 1 (positive and negative) should be used to determine the fibre-related uncertainty. The uncertainty shall also include the uncertainty in measuring the fibre outputs with the working standard, caused for example by the effects of non-uniformity, beam divergence and multiple reflections on the working standard.

In these measurements, a significant type A uncertainty may be caused by "speckles", in conjunction with the non-uniformity of the optical input port. Speckles are irregular irradiance distributions caused by interference between different modes in a multimode fibre. This effect occurs particularly when the fibre is excited by the (highly coherent) radiation from a laser diode. This uncertainty can be reduced by averaging a series of measurement results, in which each sample is taken after a slight movement of the fibre. Fibre movement will change the speckle pattern. Note this may be accompanied by a change of the total radiant power, because of a change of the reflected power and the laser diode sensitivity to reflected power.

Speckles do not exist in single-mode fibres when the exciting wavelength is sufficiently longer than the fibre's cut-off wavelength. Another possibility of eliminating the speckle pattern is using a less coherent source, such as a filtered LED or a filtered "white" radiation source.

6.3.5.2 Measurement of open-beam dependence

Similar to measuring the fibre dependence, the dependence on the spot diameter (3.31) and the numerical aperture (3.17) of an open beam can be evaluated by comparison with a working standard that exhibits a uniform large area detector and negligible angle dependence.

To address the problem of combined dependence on spot diameter and numerical aperture, it may be sufficient to evaluate:

a) the relative change of response (against the response at calibration conditions) due to excitation with the specified smallest spot diameter – smallest numerical aperture; and
b) the relative change of response due to excitation with the specified largest spot diameter-largest numerical aperture.

6.3.6 Dependence on the connector-adapter combination

This subclause discusses the test meter's dependence on multiple reflections between the optical input port and the radiation source (for example an optical connector or other mechanical parts in the beam path between the source and the optical input port). Note that the reflections may be specular or diffuse.

The relative change of response should be measured with the help of a working standard that exhibits negligible angle-dependence and surface reflections. The fibre should be the one of the calibration conditions. It is advisable to hold the fibre end in place during the measurement, in order to avoid any bending-induced changes of the power level.

Step 1: the reference beam geometry (respectively the reference fibre), together with the reference connector-adapter combination, is measured with both the working standard and the test meter, and the difference is (mathematically) adjusted to zero.

Step 2: the above procedure is applied to all specified connector-adapter combinations, by repeating each connection several times to reduce type A uncertainties. The largest relative change of response against step 1 (positive and negative) should be used to determine the uncertainty. The uncertainty shall also include the type B uncertainty in measuring the various combinations with the working standard, caused for example by multiple reflections on the working standard.

Referring to the last paragraph of 6.3.1, it also may be necessary to measure the dependence with the highest-order fibre, as listed in 6.3.5.1. A high-order fibre will create a larger image on the optical reference plane, and therefore make limitations in the positioning accuracy more obvious. In this case, an increased dependence should be recorded.

6.3.7 Dependence on wavelength

The relative change of spectral response against the response at the calibration wavelength should be measured. These measurements will normally be carried out using a spectrally continuous source imaged through a spectrally discriminating instrument, for example a monochromator or a number of spectral filters. The stray light, that is light not at the selected wavelength, should be evaluated, in order to ensure accurate measurement results. The centroidal wavelength(s) and the spectral bandwidth(s) should also be measured. The bandwidth should be narrow, because a wide bandwidth in conjunction with a strong curvature of the test meter's wavelength dependence is capable of producing erroneous measurement results. Note that extremely narrow spectral bandwidth may cause optical interference problems, that is comb-like wavelength dependence, when the beam path contains one or more optical resonators.

The beam geometry should be one of the calibration conditions. It may be possible to substitute a fibre beam using a combination of lenses and apertures. In this case, care should be taken to match the irradiated spot diameter and position on the optical reference plane with those achieved using a fibre input. Care should also be taken to ensure that back reflections from the optical input port do not add uncertainties to the measurement results.

The measurement should be carried out by direct comparison with a working standard by using the substitution technique. The working standard should have been calibrated for relative spectral response.

Because of the relatively low power levels in these measurements, *zero adjustment* of both power meters is essential. If the instrument comprises means of correction, for example a calibration curve or a table stored in a memory, the relative change of response from the **corrected** response has to be measured.

Changing the temperature may strongly influence the wavelength-dependence. For example, the wavelength-dependence of a germanium photodiode at 1 550 nm is much stronger at 0 °C than at room temperature. In general, the wavelength uncertainty shall be calculated on the basis of the largest wavelength-dependence, in this case the one at 0 °C.

6.3.7.1 Dependence on wavelength due to Fabry-Perot type interference

When using a narrow spectral bandwidth laser (B << 1 nm), the spectral response can sometimes vary rapidly with respect with wavelength as depicted in Figure 7. This is usually caused by Fabry-Perot cavity(ies) in the optical path to the detector. Fabry-Perot cavities can occur between the two faces of the window in the detector cap, between one face of the window and the detector itself, or, if a fibre is used, between the end of the fibre and any of the other surfaces.

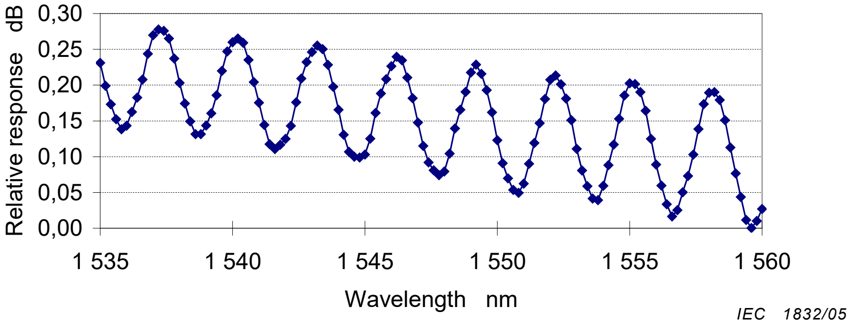


Figure 7 – Wavelength dependence of response due to Fabry-Perot type interference

In Figure 7, the peak-to-peak variation reaches Δ_{dB} = 0,2 dB ($\Delta_{\%}$ = 4,6 %) which is very important. The standard uncertainty due to optical interference is the standard deviation of the sine pattern.

$$u_{\text{int}} = \frac{1}{\sqrt{2}} \times \frac{\Delta_{\%}}{2} = 1{,}6\ \% \qquad (36)$$

6.3.8 Dependence on spectral bandwidth

This dependence increases with the curvature of the detector's wavelength dependence. The relative change of response as a function of the spectral bandwidth of the source has to be tested within the specified range of spectral bandwidths. A monochromator can be used to generate a variable spectral bandwidth; the actual power level should be measured with a working standard with negligible wavelength-dependence. The spectral-bandwidth dependence can also be evaluated by mathematical analysis, based on the known spectral response of the test meter and on the known spectral characteristics of the source.

6.3.9 Dependence on polarization

A method of evaluation of the polarization dependent response (3.22) of the test meter is to measure the response of the meter multiple times at different states of polarization. A stable light source polarized to nearly 100 % should be used, otherwise use a polarizer after the source as shown in Figure 8. A polarization controller is used to convert the fixed input polarization state to all possible output states.

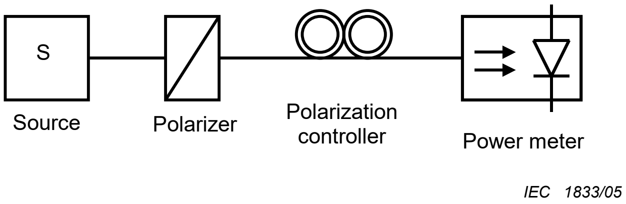


Figure 8 – Measurement setup of polarization dependent response

The source power instability and the loss variation of the polarization controller should be far smaller than the polarization dependence of the test meter. This should be verified by replacing the test meter with a detector with very low polarisation dependent response.

NOTE The laser sources may react with unstable power when light with varying polarization state is back-reflected; therefore, an attenuator or isolator may have to be inserted between the source and the polarization controller.

Another PDR measurement method, the matrix method, can be adapted from the polarization dependent loss (PDL) measurement method in IEC 61300-3-12, as described in [3].

6.3.10 Other dependences

Depending on the type of test meter, there may be dependences on other parameters. These should also be characterized as relative changes of response against the response at the calibration conditions.

One example may be including intensity-modulated optical signals into the operating conditions, in the form of specifying a range of modulation frequencies and duty cycles, and evaluating the type B uncertainty due to the modulation. Be aware that extreme duty cycles are capable of saturating the detector, the electronics or both.

7 Nonlinearity calibration

7.1 General

The nonlinearity (3.16) of the power meter should be calibrated to ensure accurate measurements at power levels away from the calibration level and for relative measurements such as loss and gain measurements. The calibration should be made by increasing and decreasing the power level to detect nonlinearities at the boundaries of each amplifier range or, whenever possible, to include measurement results at both sides of each range boundaries, in order to include nonlinearities at these boundaries. Be aware that the detector nonlinearity is dependent on the wavelength. As an example, an InGaAs detector that is linear at 1 310 nm and 1 550 nm may be nonlinear at 850 nm.

Several methods are possible. The superposition method is the reference method, as it is the most accurate and does not require a reference standard (self-calibrating method). However, the used power steps of 2 (about 3 dB) might be too large to detect nonlinearities that might appear at amplifier range boundaries. This limitation may be avoided by starting the calibration from several reference powers, or by taking separate measurements of the same power level on both sides of the amplifier range boundaries.

All methods use sources with selectable power level, for example (stabilized) laser diode sources and variable attenuators. The generated power levels should cover the specified measuring range (3.13). During the test, the maximum permissible irradiance of the input port should be defined by the optical power at the upper end of the measuring range and by single-mode fibre excitation.

The power level saturating the detector is dependent on the beam geometry. A small spot diameter may saturate the detector at lower power than a larger spot diameter.

NOTE Extreme ambient temperatures may increase the nonlinearity. Referring to the statement on "dependence on more than one operating condition" in 6.3, it may be necessary to additionally measure the nonlinearity at the extremes of the operating temperature range, and to record an increased uncertainty at operating conditions.

7.2 Nonlinearity calibration based on superposition

Highly accurate nonlinearity calibration is possible with the superposition method (also known as the addition method) [4-5]. A “fibred” version of the open-beam double aperture method [6-7] may be used with single-mode fibres. A possible setup is illustrated in Figure 9. The power is split into two different paths where shutters are located and then recombined on the power meter under test.

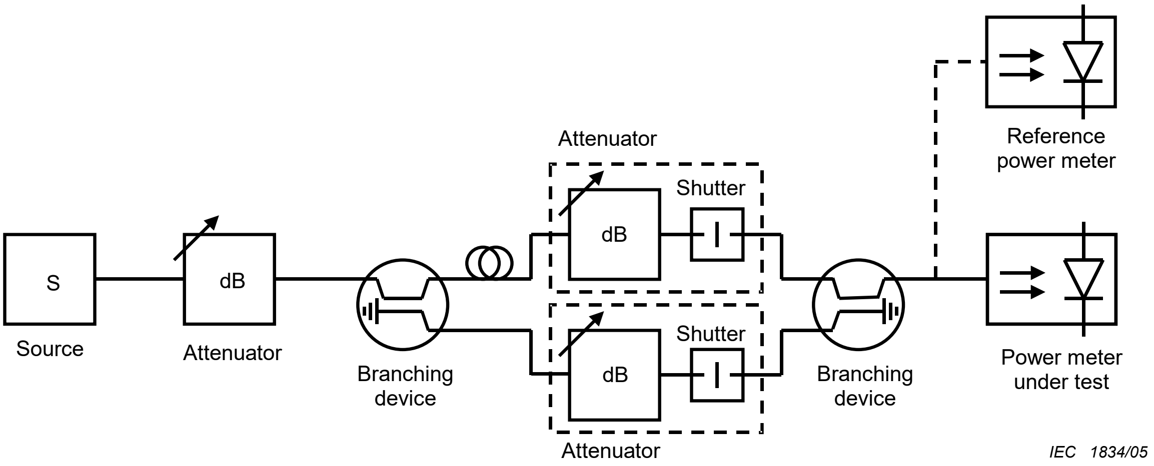


Figure 9 – Nonlinearity calibration based on superposition

Stable, optically-isolated (to reduce sensitivity to reflections) DFB lasers can be used, provided that the linewidth is broadened to yield an optimized coherence, as with the procedure for the absolute calibration. The two paths of the setup should have different lengths (around 100 m for DFB lasers) to avoid (Mach-Zehnder-type) interference fluctuations, and unused branches of branching devices shall be terminated. The drawback of this method is its higher insertion loss: typically around 1,5 dB for the first attenuator, 0,5 dB for the first branching device, 1,5 dB for the second attenuators and about 3,5 dB for the combining branching device for a total of about 7 dB. For higher power measurements, an optional optical amplifier (like an EDFA for the 1,55 µm band) can be inserted between the source and the first attenuator.

7.2.1 Procedure

(1) Set the attenuators in the two paths so that the power measured on the meter is the same when light is coming from one path or from the other path.

(2) Open both shutters and measure the total power from both paths simultaneously: $P_{\mathrm{ab,i}}$.

(3) Close the shutter on path b and measure the power from the path a: $P_{\mathrm{a,i}}$.

(4) Close the shutter on path a, open the shutter on path b and measure the power from the path b: $P_{\mathrm{b,i}}$.

(5) If the sum of the individual powers is not equal to the total power, there is a nonlinearity:

$$NL_{\mathrm{i}} = 10 \times \log_{10} \frac{P_{\mathrm{ab,i}}}{P_{\mathrm{a,i}} + P_{\mathrm{b,i}}} \quad \text{(dB)} \tag{37}$$

(6) Using the first attenuator, attenuate the total power by a factor 2 (10 $\log_{10} 2 \cong 3{,}01$ dB) to the level of the individual powers of the preceding step.

(7) Repeat steps (2) to (6) through all the desired range.

(8) At the end, the global nonlinearity is the sum of all the local nonlinearities expressed in decibels (dB), starting calculations from the reference power level where the nonlinearity is zero (higher order terms are neglected).

$$NL_{\text{global}}(P_{\text{n}}) = -\sum_{i=0}^{n+1} NL_{\text{i}} \qquad \text{for } n = -1, -2, -3, \text{ etc.} \qquad (38)$$

$$NL_{\text{global}}(P_0) = 0 \qquad \text{(reference power)}$$

$$NL_{\text{global}}(P_{\text{n}}) = +\sum_{i=1}^{n} NL_{\text{i}} \qquad \text{for } n = 1, 2, 3, \text{ etc.}$$

where

$n < 0$ indicates power levels lower than the reference power;

$n > 0$ indicates power levels higher than the reference power;

NL_{i} is the local nonlinearity for the i^{th} step (i = 0 for the step where P_{ab} is the reference power).

The result is a list of global nonlinearities for the whole power range in steps of 3,01 dB:

Table 2 – Nonlinearity

i	$P_{\text{a,i}}$ (W)	$P_{\text{b,i}}$ (W)	$P_{\text{a,i}} + P_{\text{b,i}}$ (W)	$P_{\text{ab,i}}$ (W)	NL_{i} (dB)	$NL_{\text{global}}(P_{\text{ab,i}})$ (dB)
2					NL_2	$NL_1 + NL_2$
1					NL_1	NL_1
0				P_0	NL_0	0
-1					NL_{-1}	$-NL_0$
-2					NL_{-2}	$-NL_0 - NL_{-1}$

The largest nonlinearity relative to the reference power is:

$$NL_{\text{max}} = \pm\max(|NL_{\text{global}}|) \text{ (dB)} \qquad (39)$$

This result of the nonlinearity calibration can be included in the test meter's calibration certificate or calibration report described in 5.5. If desired, NL_{max} may be separately reported together with its applicable uncertainty as calculated in the next subclause.

7.2.2 Uncertainties

Typical possible uncertainties of this method include all possible power fluctuations during a set of the three measurements such as source fluctuations due to drifts or sensitivity to changing reflections, instabilities due to interference if the coherence length of the laser is too large, polarization sensitivity and resolution of the power meter. These errors for each step are cumulative and will add to the errors of the preceding steps.

Another uncertainty is the inequivalence between the individual powers of each step and also with the total power of the next step. If the individual powers are not properly balanced, the result will not be reliable. For this last reason, the use of the optional attenuator in each path is recommended, as showed in Figure 9 (the shutter is usually included in the attenuator). They allow the power in each path to be balanced at the beginning of the measurements. Another version of the setup uses this approach, but employs two separate laser sources directly connected to the second and third attenuators respectively. It has the advantage to start measurements at higher powers but it requires communication with the test meter to adjust the attenuators at each step.

Calculate first the combined standard uncertainty for the local nonlinearity (one step) $u(NL_\mathrm{i})$ by root-sum-squaring all relevant standard uncertainty contribution. Then calculate the standard uncertainty of the global nonlinearity with:

$$u(NL_\mathrm{global}) = \sqrt{n} \times u(NL_\mathrm{i}) \text{ (dB)} \quad (40)$$

where n is the number of 3,01 dB steps counted from the reference level.

7.3 Nonlinearity calibration based on comparison with a calibrated power meter

One possible measurement method is direct comparison of the test meter with a reference meter by using the substitution technique. The reference meter is used to determine the output power. Then the reference meter is replaced by the test meter. The measurement results of both meters are recorded. In this case, errors can be due to the repeatability of the attenuator, its PDL, the source power stability and the nonlinearity of the reference meter. The nonlinearity of the reference meter should have been calibrated using a more accurate method.

It is advisable to repeat the measurements with the working standard to check for drifts in the measurement. In order to extend the measurements to low power levels it is recommended that the reference meter incorporates a low noise detector.

Instead of the substitution, simultaneous excitation of both the standard and the test meter, with the help of an appropriate beam splitter or branching device is also possible. A beam splitter/branching device with an asymmetric ratio, or the use of a second attenuator, will allow an extension of the dynamic range of the measurement into both directions. The dependence of the ratio to the power level and polarization has to be investigated.

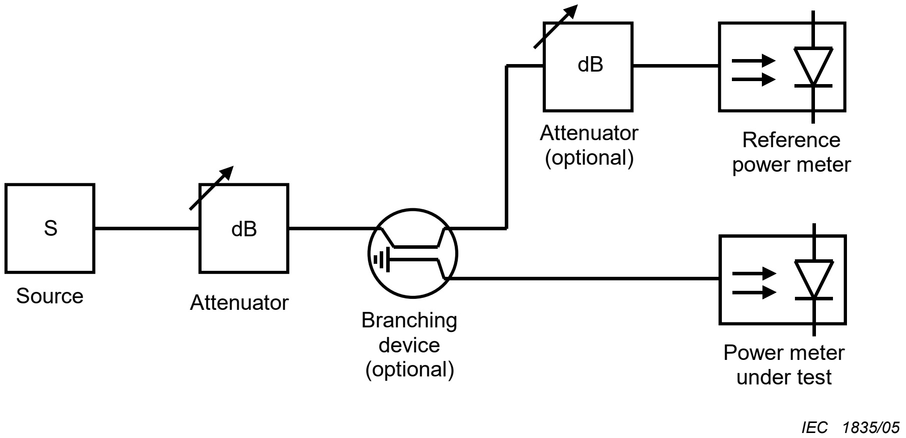


Figure 10 – Measurement setup for nonlinearity calibration by comparison

7.3.1 Procedure

(1) Set the desired reference power with the help of the first attenuator.

(2) Measure the *radiant power* with the reference meter $P_\mathrm{ref,0}$ and with the test meter $P_\mathrm{DUT,0}$.

(3) Increase (or decrease) the power with the help of the first attenuator and record the power measured with the reference meter $P_\mathrm{ref,i}$ and with the test meter $P_\mathrm{DUT,i}$.

(4) Calculate the nonlinearity:

$$NL_{\mathrm{i}} = 10 \times \log_{10} \frac{P_{\mathrm{DUT,i}}}{P_{\mathrm{DUT,0}}} - 10 \times \log_{10} \frac{P_{\mathrm{ref,i}}}{P_{\mathrm{ref,0}}} \ (\mathrm{dB}) \qquad (41)$$

(5) Repeat steps (3) to (4) to cover the measurement range.

7.3.2 Uncertainties

Possible sources of measurement uncertainties are given in the following list, it may not be complete. Additional contributions may have to be taken into account, depending on the measurement setup and procedure. The mathematical basis, Annex A, should be used to calculate and state the uncertainties.

a) nonlinearity of the linearity standard (usually calibrated by the superposition method);

b) source instability (back-reflections may cause source instability);

c) optical interference (the coherence length of the source should be smaller than the distance between reflection points);

d) polarization dependence of the components;

e) resolution of the test meter;

f) stability of the ratio of the beam splitter or the branching device if used;

g) depending on the procedure, the repeatability of the attenuator.

7.4 Nonlinearity calibration based on comparison with an attenuator

The simplest but least accurate method to measure the nonlinearity, is based on varying the power level with a calibrated attenuator. The traceability chain (3.34) of the attenuator shall be determined. Care shall be taken in the calculation of the uncertainty since the calibration of the attenuator is itself based on the linearity of a calibrated power meter. This method does not require a second power meter; instead, the reference power levels can then be calculated with the known attenuation of the attenuator. The main errors arise from the nonlinearity of the variable attenuator, its PDL in the case of single-mode fibres and the source power stability. Be also aware of the attenuator's repeatability and wavelength-dependence. This method is nevertheless useful when high accuracy is not necessary because it is simple and because the low insertion loss (only the loss of the attenuator) permits to measure at higher power than other methods (up to the maximum input power at which the attenuator remains linear).

7.5 Calibration of power meter for high power measurement

Most photoelectric detectors become nonlinear above an optical power of about 10 mW. Sensors designed to measure power at higher power usually incorporate an attenuator in front of the detector.

Absolute power calibration at high power [8] is not available widely. When not possible, it is then necessary to calibrate the nonlinearity of the power meter up to high power. In this context, high power is defined as powers greater than 10 mW. It is not straightforward to use the same setup as described in the previous clauses since several components may exhibit nonlinear effects. The behaviour at high power of all elements in the calibration setup (connectors, attenuators, branching devices, etc.) should be investigated. The superposition method is the preferred method, since it does not rely on a reference standard, but notice that the use of a long length of fibre in one path of the superposition system is not desirable at high powers due to the possibility of nonlinear effects causing apparent nonlinearity of the power meter.

Annex A
(normative)

Mathematical basis for measurement uncertainty calculations

A.1General

This annex summaries the form of evaluating, combining and reporting the uncertainty of measurement. It is based on the "Guide to the expression of uncertainty in measurement" (GUM). It does not relieve the need to consult this guide for more advice.

This standard distinguishes two types of evaluation of uncertainty of measurement. Type A is the method of evaluation of uncertainty by the statistical analysis of a series of measurements on the same measurand. Type B is the method of evaluation of uncertainty based on other knowledge.

A.2Type A evaluation of uncertainty

The type A evaluation of standard uncertainty can be applied when several independent observations have been made for a quantity under the same conditions of measurement.

For a quantity X estimated from n independent repeated observations X_k, the arithmetic mean is:

$$\overline{X} = \frac{1}{n}\sum_{k=1}^{n} X_\mathrm{k} \qquad \text{(A.1)}$$

This mean is used as the estimate of the quantity, that is $x = \overline{X}$. The experimental standard deviation of the observations is given by:

$$s(X) = \left[\frac{1}{n-1}\sum_{k=1}^{n}\left(X_\mathrm{k} - \overline{X}\right)^2\right]^{1/2} \qquad \text{(A.2)}$$

where:

$\overline{X}$ is the arithmetic mean of the observed values;

X_k are the measurement samples of a series of measurements;

n is the number of measurements; it is assumed to be large, for example, $n \geq 10$.

The type A standard uncertainty $u_\mathrm{typeA}(x)$ associated with the estimate x is the experimental standard deviation of the mean:

$$u_\mathrm{typeA}(x) = s(\overline{X}) = \frac{s(X)}{\sqrt{n}} \qquad \text{(A.3)}$$

A.3Type B evaluation of uncertainty

The type B evaluation of standard uncertainty is the method of evaluating the uncertainty by means other than the statistical analysis of a series of observations. It is evaluated by scientific judgement based on all available information on the variability of the quantity.

If the estimate x of a quantity X is taken from a manufacturer's specification, calibration certificate, handbook, or other source and its quoted uncertainty $U(x)$ is stated to be a multiple k of a standard deviation, the standard uncertainty $u(x)$ is simply the quoted value divided by the multiplier.

$$u(x) = U(x) \,/\, k \tag{A.4}$$

If only upper and lower limit X_{max} and X_{min} can be estimated for the value of the quantity X, a rectangular probability distribution is assumed.

The standard uncertainty is

$$u(x) = \frac{\left(\left|X_{\mathrm{max}} - x\right|, \left|X_{\mathrm{min}} - x\right|\right)_{MAX}}{\sqrt{3}} \tag{A.5}$$

The contribution to the standard uncertainty associated with the output estimate y resulting from the standard uncertainty associated with the input estimate x is

$$u(y) = c \times u(x) \tag{A.6}$$

where c is the **sensitivity coefficient** associated with the input estimate x, that is the partial derivative of the model function $y(x)$, evaluated at the input estimate x.

$$c = \frac{\partial y}{\partial x} \tag{A.7}$$

The sensitivity coefficient c describes the extent to which the output estimate y is influenced by variations of the input estimate x. It can be evaluated by Equation (A.7) or by using numerical methods, that is by calculating the change in the output estimate y due to a change in the input estimate x from a model function. Sometimes it may be more appropriate to find the change in the output estimate y due to the change of x from an experiment.

A.4 Determining the combined standard uncertainty

The combined standard uncertainty is used to collect a number of individual uncertainties into a single number. The combined standard uncertainty is based on statistical independence of the individual uncertainties; it is calculated by root-sum-squaring all standard uncertainties obtained from type A and type B evaluation:

$$u_{\mathrm{c}}(y) = \sqrt{\sum_{i=1}^{n} u_i^2(y)} \tag{A.8}$$

where

i is the current number of individual contribution;

$u_i(y)$ are the standard uncertainty contributions;

n is the number of uncertainties.

NOTE It is acceptable to neglect uncertainty contributions to this equation that are smaller than 1/10 of the largest contribution, because squaring them will reduce their significance to 1/100 of the largest contribution.

When the quantities above are to be used as the basis for further uncertainty computations, then the combined standard uncertainty, u_c, can be re-inserted into Equation (A.8). Despite its partially type A origin, u_c should be considered as describing an uncertainty of type B.

A.5 Reporting

In calibration reports and technical data sheets, combined standard uncertainties shall be reported in the form of expanded uncertainties, together with the applicable level of confidence. Correction factors or deviations shall be reported. The expanded uncertainty U is obtained by multiplying the standard uncertainty $u_c(y)$ by a coverage factor k:

$$U = k \times u_c(y) \tag{A.9}$$

For a level of confidence of approximately 95 %, the default level, then $k = 2$. If a level of confidence of approximately 99 % is chosen, then $k = 3$. The above values for k are valid under some conditions, see GUM; if these conditions are not met, larger coverage factors are to be used to reach these levels of confidence.

Annex B
(informative)

Linear to dB scale conversion of uncertainties

B.1 Definition of decibel

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

$$L_{P/P_0} = 10 \times \log_{10}\left(\frac{P}{P_0}\right)(\text{dB}) \tag{B.1}$$

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

B.2 Conversion of relative uncertainties

Similar to the previous definition, relative uncertainties, U_{lin}, or relative deviations, can be expressed in decibels:

$$U_{\text{dB}} = 10 \times \log_{10}(1 + U_{\%}) \tag{B.2}$$

Reciprocally, U_{lin} can be expressed in % using:

$$U_{\%} = \left[10^{\left(\frac{U_{\text{dB}}}{10}\right)} - 1\right] \times 100 \tag{B.3}$$

For small values of U_{lin}, the first term of the applicable Taylor series can be used. Having:

$$\ln(1+x) = \sum_{n=1}^{\infty} \frac{-1^{n+1}}{n} x^n \text{ and } \log_{10} x = \frac{\ln x}{\ln(10)} \tag{B.4}$$

that leads to:

$$U_{\text{dB}} = \frac{10}{\ln(10)} \sum_{n=1}^{\infty} \frac{-1^{n+1}}{n} {U_{\text{lin}}}^n \approx \frac{10}{\ln(10)} U_{\text{lin}} \tag{B.5}$$

and two useful expressions:

$$U_{\text{dB}} \approx 4{,}34 \times U_{\text{lin}} \Leftrightarrow U_{\text{lin}} \approx 0{,}23 \times U_{\text{dB}} \tag{B.6}$$

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IEC 60793-1-43, *Optical fibres – Part 1-43: Measurement methods and test procedures – Numerical aperture measurement*

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IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems*

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IEC TR 61930, *Fibre optic graphical symbology*

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*

86/514/CD

COMMITTEE DRAFT (CD)

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DATE OF CIRCULATION: **2017-04-07**	CLOSING DATE FOR COMMENTS: **2017-06-30**
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SECRETARIAT: United States of America	SECRETARY: Mr Steve Swanson
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TITLE:

Calibration of wavelength/optical frequency measurement instruments - Part 3:Optical frequency meters internally referenced to a frequency comb

NOTE FROM TC/SC OFFICERS:

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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CALIBRATION OF WAVELENGTH / OPTICAL FREQUENCY MEASUREMENT INSTRUMENTS –

Part 3: Optical frequency meters internally referenced to a frequency comb

FOREWORD

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International Standard IEC 62129-3 has been prepared by IEC technical committee 86: Fibre optics.

The text of this standard is based on the technical specification IEC TS 62129-3.

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

A list of all parts in the IEC 62129 series, published under the general title *Calibration of wavelength/optical frequency measurements instruments*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

The National Committees are requested to note that for this publication the stability date is 2020.

THIS TEXT IS INCLUDED FOR THE INFORMATION OF THE NATIONAL COMMITTEES AND WILL BE DELETED AT THE PUBLICATION STAGE.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

It is essential for realizing fibre optic systems that optical channels are defined in the optical frequency domain, not the wavelength domain. One example: the anchor frequency of the ITU-T grid is 193,1 THz, and the channel spacings of the ITU-T grid are 12,5 GHz, 25 GHz, 50 GHz, and 100 GHz [1][1].

ITU-T has also discussed λ-interface systems such as "black link" [2]. "Black link" includes WDM MUX/DEMUX and a transmission fibre, and provides λ-interfaces. Especially in DWDM systems (channel spacing $<$100 GHz), the uncertainty in specifying optical frequency needs to be minimized.

To implement future telecom systems, it is expected that optical frequency measurements will need to be extremely precise. For example, to achieve the channel spacing of 25 GHz, signal optical frequency uncertainty (Uf_{sig}) and required measurement uncertainty (Uf_{meas}) need to be 2 GHz to 200 MHz (Uf_{sig} / f = 10^{-5} to 10^{-6}) and 200 MHz to 2 MHz (Uf_{meas} / f = 10^{-6} to 10^{-8}), respectively. Unfortunately, conventional wavelength meters have measurement uncertainties of 10^{-6} to 10^{-7}. The solution is to use optical frequency measurements since measurement uncertainties can be as small as 10^{-9}, which satisfies the above telecom requirement (Uf_{meas} / f = 10^{-6} to 10^{-8}). Therefore, an optical frequency measurement scheme is necessary for the calibration of future telecom systems.

The frequency meter to calibrate with the procedure described in this international standard is the measurement equipment internally utilizing optical frequency comb. In Annex A, the mathematical basis for the uncertainty of measurement is described. The measurement procedure of the frequency with the frequency meter utilizing optical frequency comb is shown in Annex B and the uncertainty depending on the frequency is shown in Annex C. Additionally, the example of the optical frequency comb sources are shown in Annex D.

This international standard defines all of the steps involved in the calibration process of the frequency measuring with the optical frequency meter internally utilizing optical frequency comb: establishing the calibration conditions, carrying out the calibration, calculating the uncertainty, and reporting the uncertainty, the calibration conditions and the traceability.

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[1] Numbers between square brackets refer to the Bibliography.

CALIBRATION OF WAVELENGTH/ OPTICAL FREQUENCY MEASUREMENT INSTRUMENTS –

Part 3: Optical frequency meters internally referenced to a frequency comb

1 Scope

This part of IEC 62129 describes the calibration of optical frequency meters. It is applicable to instruments measuring the optical frequency emitted from sources that are typical for the fibre-optic communications industry. It is assumed that the optical radiation will be coupled to the optical frequency meter by a single-mode optical fibre.

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 60793-2-50, *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*

IEC TR 61931, *Fibre optic – Terminology*

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

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

For the purposes of this document, the terms and definitions contained in IEC TR 61931, as well as the following terms and definitions, 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 measurement standards

3.2
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.

[SOURCE: ISO/IEC Guide 99:2007, 2.39, modified – only the first part of the definition is used] [3]

3.3
national (measurement) standard
measurement standard recognized by a national decision to serve, in a country, as the basis for assigning values to other measurement standards of the quantity concerned

[Related to ISO/IEC Guide 99:2007, 5.3]

3.4
national standards laboratory
laboratory which maintains the national measurement standard

3.5
reference standard
measurement standard, generally having the highest metrological quality available at a given location or in a given organization, from which measurements made there are derived

[Related to ISO/IEC Guide 99:2007, 5.6]

3.6
traceability
property of the result of a measurement or the value of a measurement standard whereby it can be related to stated references, usually national or international measurement standards, through an unbroken chain of comparisons all having stated uncertainties

[Related to ISO/IEC Guide 99:2007, 2.41]

3.7
traceability chain
unbroken chain of comparison

[Related to ISO/IEC Guide 99:2007, 2.42]

3.8
working standard
measurement 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.

[Related to ISO/IEC Guide 99:2007, 5.7].

4 Calibration test requirements

4.1 Preparation

The following recommendations apply.

The calibration laboratory should satisfy requirements of ISO/IEC 17025.

There should be a documented measurement procedure for each type of calibration performed, giving step-by-step operating instructions and equipment to be used.

The environmental conditions shall be commensurate with the degree of uncertainty that is required for calibration:

a) the environment shall be clean;
b) temperature monitoring and control is required;
c) all laser sources shall be safely operated (refer to IEC 60825-1 and IEC 60825-2).

Perform all tests at an ambient room temperature of 23 °C ± 3 °C with a relative humidity of (50 ± 20) % unless otherwise specified. Give the test equipment a minimum of 2 h prior to testing to reach equilibrium with its environment. Allow the optical frequency meter a warm-up period in accordance with the manufacturer’s instructions.

4.2 Reference test conditions

The reference test conditions usually include the following parameters and, if necessary, their tolerance bands: date, temperature, relative humidity, displayed power level, displayed optical frequency, fibre, connector-adapter combination, (spectral) bandwidth and resolution bandwidth (spectral resolution) set. Unless otherwise specified, use a single-mode optical fibre input pigtail as prescribed by IEC 60793-2-50, having a length of at least 2 m.

Operate the optical frequency meter in accordance with the manufacturer’s specifications and operating procedures. Where practical, select a range of test conditions and parameters which emulate the actual field operating conditions of the optical frequency meter under test. Choose these parameters so as to optimize the optical frequency meter’s uncertainties, as specified by the manufacturer’s operating procedures.

NOTE The calibration results only apply to the set of test conditions used in the calibration process.

4.3 Traceability

The requirements of ISO/IEC 17025 should be met.

Make sure that any test equipment which has a significant influence on the calibration results is calibrated. Upon request, specify this test equipment and its calibration chain(s). The recalibration period(s) shall be defined and documented.

5 Optical frequency calibration

5.1 Establishing the calibration conditions

Establishing and maintaining the calibration conditions is an important part of the calibration, because any change of these conditions is capable of producing erroneous measurement results. The calibration conditions should be a close approximation to the intended operating conditions. This ensures that the (additional) uncertainty in the operating environment is as small as possible. The calibration conditions should be specified in the form of nominal values with uncertainties when applicable. In order to meet the requirements of this standard, the calibration conditions shall at least consist of:

a) date of calibration;

b) ambient temperature, with uncertainty, for example 23 °C ± 3 °C. The temperature may need to be monitored continuously to ensure that it remains within the prescribed limits;

c) ambient relative humidity, for example 30 % – 70 %. The ambient relative humidity may need to be monitored continuously to ensure that it remains within the prescribed limits. A relative humidity below the condensation point is assumed by default;

d) input optical power (that has to fall within the allowable specification for the optical frequency meters);

e) if a transition locked source is used, then the quality of the lock shall be continuously monitored during the measurements; a lock indicator can be sufficient.

The above conditions may not be exhaustive. There may be other parameters that have a significant influence on the measurement uncertainty and therefore should be reported, too.

5.2 Calibration procedure

5.2.1 General

The main steps of the calibration procedure are as follows:

a) establish and record the appropriate measurement conditions (see 5.1 a)~c)). Switch on all instrumentation and wait for enough time to stabilize;

b) set up the reference source with condition 5.2 d);

c) set up the instrument state of the test optical frequency meter according to the instruction manual. Select appropriate units;

d) record the instrument states of the optical frequency meter.

5.2.2 Measurement configuration

For calibration laboratories, a stabilized laser can be utilized as a reference source.

Figure 1 shows the configuration using the reference source. The temperature of the environment is monitored.

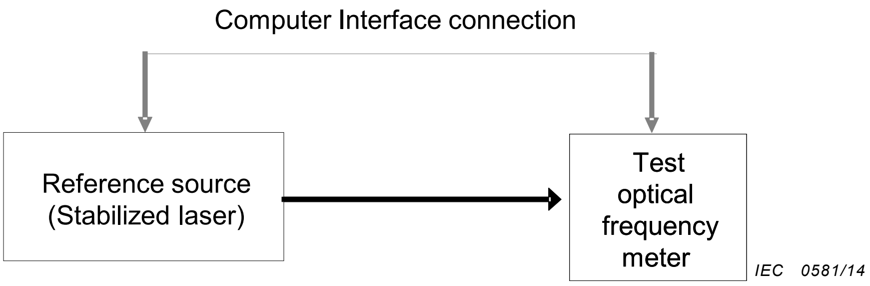
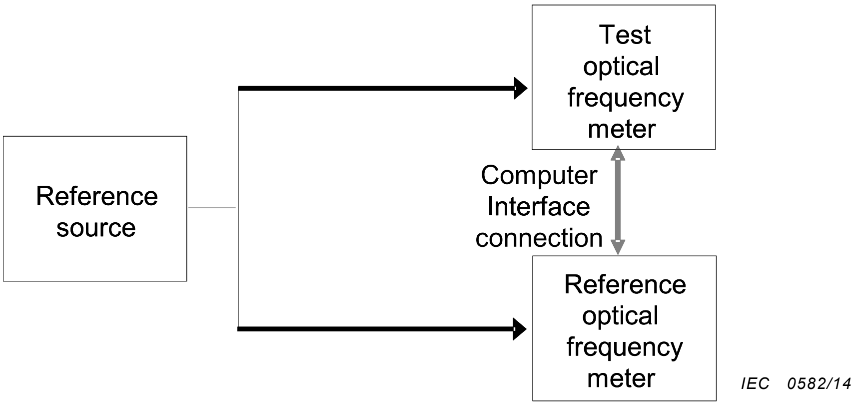


Figure 1 – Optical frequency meter measurement using a reference source

Figure 2 shows the configuration using a reference optical frequency meter.

It is necessary that the measurements be performed simultaneously on both the reference and the test optical frequency meters.



1 – Optical frequency meter measurement using a reference optical frequency meter

5.2.3 Detailed procedure

Typically, 50 samples (n) are taken per measurement unless otherwise defined in the relevant specification.

The measurement process is as follows:

a) allow the equipment to reach equilibrium;
b) configure the data acquisition software;
c) ensure that the optical source is locked and is operating correctly;
d) run the data acquisition software.

The correction factor is determined from the difference between the reference optical frequency and the mean values from each measurement:

$$CF = fref - \frac{1}{n}\sum_{i=1}^{n} ftest_i \tag{1}$$

where $fref$ is the reference optical frequency and $ftest$ is the optical frequency measured by the test optical frequency meter.

5.3 Calibration uncertainty

Note that the following list may not be complete. Additional contributions may have to be taken into account, depending on the measurement setup and procedure. The mathematical basis, Annex A, should be used to calculate and state the uncertainty.

a) Source uncertainty (how well the source is stabilized to the natural standard)
b) Standard deviation of measurement samples

5.4 Reporting the results

The results of each calibration should be reported as required by ISO/IEC 17025. Calibration certificates referring to this standard shall at least include the following information:

a) all calibration conditions of the calibration process as described in 5.1;
b) the test meter's correction factor(s) or deviation(s), if the test meter was not adjusted;
c) on receipt, correction factors or deviations and, after adjustment, correction factors or deviations in the case that an adjustment was carried out;

d) the calibration uncertainty in the form of an expanded uncertainty as described in 5.2 and Annex A;

e) the instrument state of the test meter during the calibration;

f) evidence that the measurements are traceable (see 5.10.4.1c) of ISO/IEC 17025:2005).

Annex A
(normative)

Mathematical basis

A.1 General

This annex summarizes the form of evaluating, combining and reporting the uncertainty of measurement. It is based on ISO/IEC 98-3. It does not replace the need to consult this guide for more advice.

This technical specification distinguishes two types of evaluation of uncertainty of measurement. Type A is the method of evaluation of uncertainty by the statistical analysis of a series of measurements on the same measurand. Type B is the method of evaluation of uncertainty based on other knowledge.

A.2 Type A evaluation of uncertainty

Type A evaluation of standard uncertainty can be applied when several independent observations have been made for a quantity under the same conditions of measurement.

For a quantity X estimated from n independent repeated observations X_k, the arithmetic mean is

$$\overline{X} = \frac{1}{n}\sum_{k=1}^{n} X_{\mathrm{k}} \qquad \text{(A.1)}$$

This mean is used as the estimate of the quantity, that is $x = \overline{X}$. The experimental standard deviation of the observations is given by

$$s(X) = \left[\frac{1}{n-1}\sum_{k=1}^{n}\left(X_k - \overline{X}\right)^2\right]^{1/2} \qquad \text{(A.2)}$$

where

$\overline{X}$ is the arithmetic mean of the observed values;

X_k are the measurement samples of a series of measurements;

n is the number of measurements; it is assumed to be large, for example, $n \geq 10$.

The type A standard uncertainty $u_{\mathrm{typeA}}(x)$ associated with the estimate x is the experimental standard deviation of the mean

$$u_{\mathrm{typeA}}(x) = s(\overline{X}) = \frac{s(X)}{\sqrt{n}} \qquad \text{(A.3)}$$

A.3 Type B evaluation of uncertainty

Type B evaluation of standard uncertainty is the method of evaluating the uncertainty by means other than the statistical analysis of a series of observations. It is evaluated by scientific judgement based on all available information on the variability of the quantity.

If the estimate x of a quantity X is taken from a manufacturer's specification, calibration certificate, handbook, or other source and its quoted uncertainty $U(x)$ is stated to be a multiple k of a standard deviation. The standard uncertainty $u(x)$ is simply the quoted value divided by the multiplier:

$$u(x) = \frac{U(x)}{k} \quad \text{(A.4)}$$

If only upper and lower limit X_{max} and X_{min} can be estimated for the value of the quantity X, a rectangular probability distribution is assumed.

The standard uncertainty is

$$u(x) = \frac{\left(|X_{\mathrm{max}} - x|, |X_{\mathrm{min}} - x|\right)_{MAX}}{\sqrt{3}} \quad \text{(A.5)}$$

The contribution to the standard uncertainty associated with the output estimate y resulting from the standard uncertainty associated with the input estimate x is

$$u(y) = c \times u(x) \quad \text{(A.6)}$$

where c is the sensitivity coefficient associated with the input estimate x, that is the partial derivative of the model function $y(x)$, evaluated at the input estimate x.

$$c = \frac{\partial y}{\partial x} \quad \text{(A.7)}$$

The sensitivity coefficient c describes the extent to which the output estimate y is influenced by variations of the input estimate x. It can be evaluated by Equation (A.7) or by using numerical methods, i.e. by calculating the change in the output estimate y due to a change in the input estimate x from a model function. Sometimes it may be more appropriate to find the change in the output estimate y due to the change of x from an experiment.

A.4 Determining the combined standard uncertainty

Combined standard uncertainty is used to collect a number of individual uncertainties into a single number. The combined standard uncertainty is based on statistical independence of the individual uncertainties. It is calculated by root-sum-squaring all standard uncertainties obtained from type A and type B evaluation.

$$u_{\mathrm{c}}(y) = \sqrt{\sum_{i=1}^{n} u_i^2(y)} \quad \text{(A.8)}$$

where

i is the current number of individual contributions;

$u_{\mathrm{i}}(y)$ are the standard uncertainty contributions;

n is the number of uncertainties.

NOTE It is acceptable to neglect uncertainty contributions to Equation (A.9) that are smaller than 1/10 of the largest contribution because squaring them will reduce their significance to 1/100 of the largest contribution.

When the quantities above are to be used as the basis for further uncertainty computations, then the combined standard uncertainty, u_c, can be re-inserted into Equation (A.8). Despite its partially type A origin, u_c should be considered as describing an uncertainty of type B.

A.5 Reporting

In calibration reports and technical data sheets, combined standard uncertainties shall be reported in the form of expanded uncertainties, together with the applicable level of confidence. Correction factors or deviations shall be reported. The expanded uncertainty U is obtained by multiplying the standard uncertainty $u_c(y)$ by a coverage factor k

$$U = k \cdot u_c(y) \qquad \text{(A.9)}$$

For a level of confidence of approximately 95 %, the default level, then k = 2. If a level of confidence of approximately 99 % is chosen, then k = 3. The above values for k are valid under some conditions (see GUM); if these conditions are not met, larger coverage factors are to be used to reach these levels of confidence.

Annex B
(informative)

Frequency measurement of a stabilized laser with an optical frequency comb

For optical frequency measurement, equally-spaced “frequency comb” lines (spacing of up to 50 GHz) from an optical frequency comb are utilized as a “ruler” for optical frequency measurement [4 – 15]. Optical frequency measurements provide more accurate calibration than interferometric wavelength measurements in air by eliminating the effects of refractive indices.

Some examples of practical optical frequency comb are shown in Annex B.

Figure B.1 is the schematic configuration of an optical frequency measurement technique that uses optical frequency combs.

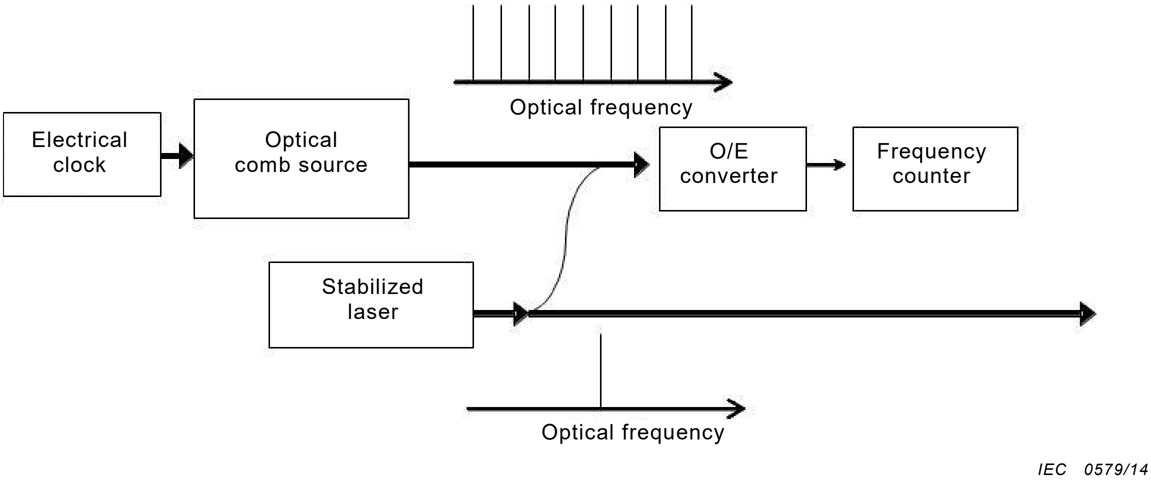


Figure B.1 – Schematic configuration of optical frequency measurement technique using an optical comb

Figure B.2 shows the optical spectrum of the laser and the optical frequency comb. The optical frequency comb generates an optical frequency comb with uniform spacing (f(comb spacing)) which is equal to the electrical clock frequency driving the optical frequency comb. f(comb spacing) is also equal to the pulse repetition rate. Thus, the uncertainty of comb spacing is proportional to the uncertainty of the electrical clock frequency. The comb spacing generally lies between 100 MHz and 25 GHz. In this case, the stabilized laser (f (stabilized laser)) output is combined with the optical frequency comb, and then these two lights are input to an optical-electrical (O/E) converter. The beat frequency (f (beat)) between the two lights is taken as the output of the O/E converter. The optical frequency (f(stabilized laser)) of the stabilized laser can be calculated by Equation (B.1).

$$f(\text{stabilized laser}) = f(N) \pm f(\text{beat}) \qquad \text{(B.1)}$$

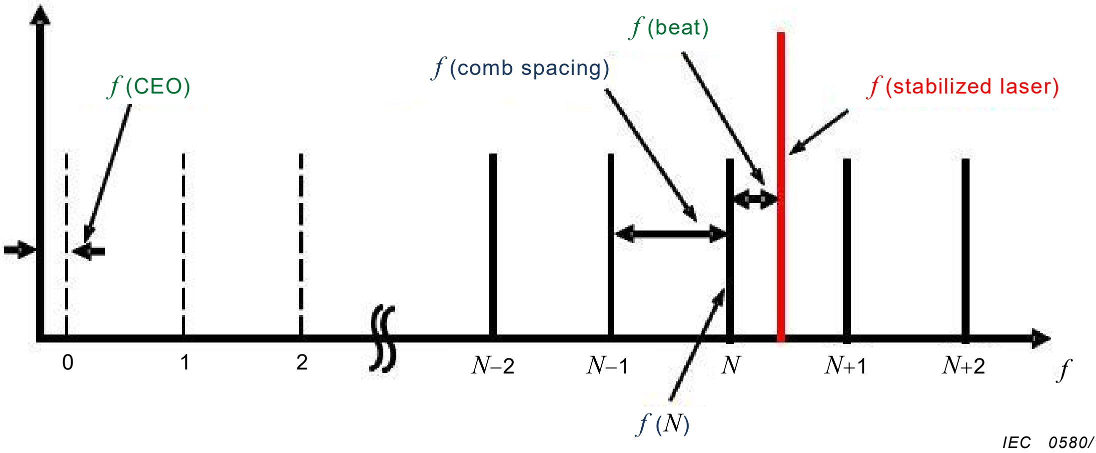
Here, $f(N)$ is the optical frequency of the N-th mode of optical frequency comb, and is the summation of f(comb spacing) and the carrier envelope offset frequency f(CEO), as shown in Equation (B.2).

$$f(N) = N \times f(\text{comb spacing}) + f(\text{CEO}) \qquad \text{(B.2)}$$

Here, N is the large integer, and can be determined with a wavelength meter. The sign of the beat frequency (+ or –) can be deduced by changing f(stabilized laser) slightly.

f(CEO) is related to the pulse-to-pulse phase shift, $\Delta\phi$, between the peak of electrical field and the peak of envelope [5], as shown in Equation (B.3).

$$f(\text{CEO}) = \left(\Delta\phi / 2\pi\right) f(\text{comb spacing}) \tag{B.3}$$



IEC 0580/14

Key

f	optical frequency
f (stabilized laser)	stabilized laser frequency
f (comb spacing)	comb spacing
f (beat)	beat frequency
f (N)	optical frequency of the N-th comb mode
f (CEO)	carrier envelope offset frequency

Figure B.2 – Optical spectra of lasers and optical frequency combs

Annex C
(informative)

Frequency-dependence of uncertainty

The uncertainty arising from the electrical clocks in Clauses D.1 to D.2 will affect the mode spacing in a way that varies with comb mode number.

From Equation (B.1)

$$f(\text{tuneable laser}) = f(\text{stabilized laser}) + N \times f(\text{comb spacing}) \pm f(\text{beat})$$

Therefore the uncertainty in the comb spacing multiplies up by N, which varies depending on the frequency of the tuneable laser under test.

For example, when the uncertainty arising from the electrical clock is less than 10^{-8} and the measurement frequency range is 5 THz, an uncertainty of less than 50 kHz can be realized within the entire measurement frequency range. However, if the uncertainty of the electrical clocks degrades to 10^{-6}, the measurement uncertainty in the frequency of 25 GHz away from the stabilized laser will be 25 kHz; whereas at a 5 THz separation, it will be 5 MHz. In this case, the frequency dependent uncertainty may exceed the measurement uncertainty required for telecom systems (i.e. 200 MHz to 2 MHz) for some frequency values.

When the uncertainty of the electrical clocks is not clear, it is recommended to test the device with a minimum of two reference frequencies: one close to the frequency of the stabilized laser, and the second reference at a widely separated frequency. From these results, the frequency dependence of the uncertainty can be calculated.

Annex D
(informative)

Examples of stabilized optical frequency comb source

D.1 Method A (pump pulse source + nonlinear optical effect)

Figure D.1 shows an optical comb system combining pump pulse source and nonlinear optical effects [4-13, 15]. The pump pulse source is driven by an electrical clock (frequency: f(clock)). The pump pulse source generates an optical pulse train with a repetition rate of f(clock). The pump pulse train is amplified when the pulse power is small. The optical pulse train is input to a nonlinear material (fibre, etc.) and the resulting spectral broadening can exceed an octave. By comparing the optical frequencies of the octave-broadened comb with that of the second harmonic, one can stabilize and measure the frequency offset (f(CEO)). The frequencies f(CEO) and f(comb spacing) are locked to the electrical clock, thus yielding a very stable optical comb without the use of an external stabilized laser. The uncertainty of the optical comb is determined by that of the electrical clock so very small values can be expected.

The pump pulse source can be realized with several sources. For example, a mode lock laser can be utilized. A titanium-doped sapphire (Ti:S) laser or a fibre laser can be used as the mode-locked laser. These optical frequency comb systems can be extended to any IR wavelength region (1 μm to 2 μm). As second example, the supercontinuum (SC) comb source can be utilized. SC is a spectral broadening phenomenon and is realized when nonlinear materials are pumped by short optical pulses. It occurs due to the combined effects of self-phase modulation, cross-phase modulation, parametric, four-wave mixing and Raman scattering. A superbroadened bandwidth of more than 200 nm (25 THz) with the spacing range from several GHz to several 10 GHz at 1,5 μm and the uncertainty of 1 MHz for 25 GHz spacing in the telecom bands has been reported[15].

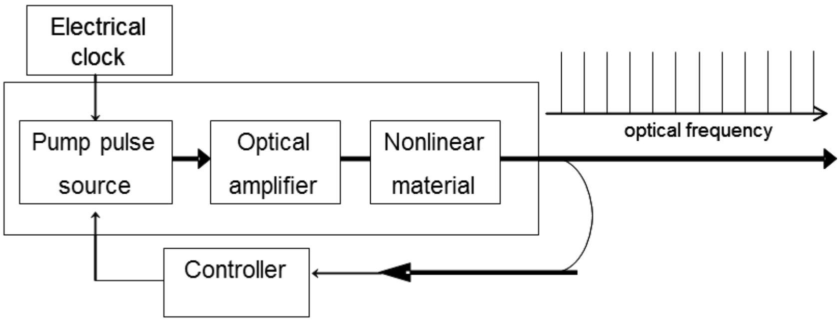
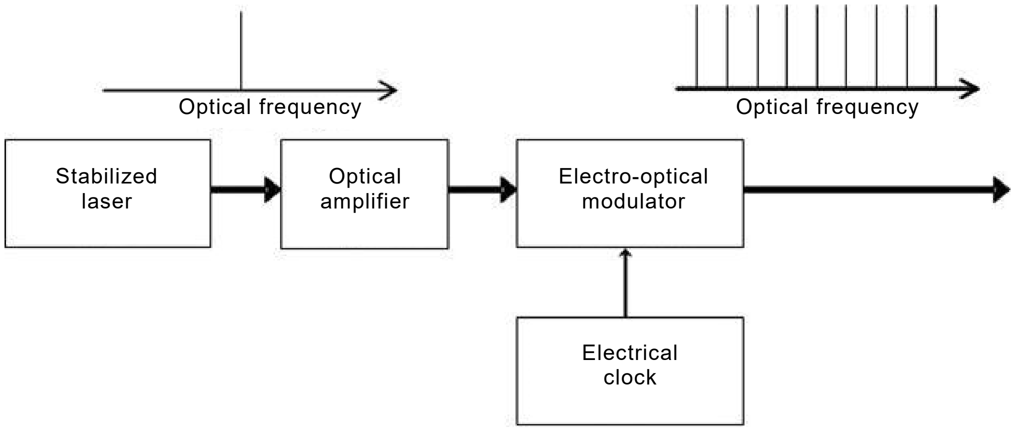


Figure D.1 – Pump pulse source + nonlinear optical effect

D.2 Method B (stabilized laser + electro-optical modulator)

Figure D.2 shows an electro-optical modulator type comb source with a stabilized laser. The stabilized laser output is amplified and then input into the electro-optical modulator which is driven by an electrical clock. This method has been reported to offer 5 THz bandwidth optical comb generation with 6,25 GHz spacing [14].



IEC 0584/14

Figure D.2 – Electro-optical modulator type comb source

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86B/4076/FDIS

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PROJECT NUMBER:

IEC 61753-121-2 ED2

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2017-03-24	**2017-05-05**

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Attention IEC-CENELEC parallel voting

The attention of IEC National Committees, members of CENELEC, is drawn to the fact that this Final Draft International Standard (FDIS) is submitted for parallel voting.

The CENELEC members are invited to vote through the CENELEC online voting system.

TITLE:

Fibre optic interconnecting devices and passive components - Performance standard - Part 121-2: Simplex and duplex cords with single-mode fibre and cylindrical ferrule connectors for category C - Controlled environment

NOTE FROM TC/SC OFFICERS:

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – PERFORMANCE STANDARD –

Part 121-2: Simplex and duplex cords with single-mode fibre and cylindrical ferrule connectors for category C – Controlled environment

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International Standard IEC 61753-121-2 has been prepared by subcommittee 86B: Fibre optic interconnecting devices and passive components, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition published in 2010. This edition constitutes a technical revision.

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

a) merge an optical performance requirement of a reference cord;
b) delete Annexes D and E due to updated relevant standard document;

c) modify the whole document structure according to the latest ISO/IEC Directives.

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

FDIS	Report on voting
86B/XX/FDIS	86B/XX/RVD

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.

A list of all parts of IEC 61753 series, published under the general title *Fibre optic interconnecting devices and passive components – Performance standard*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The National Committees are requested to note that for this document the stability date is 2025.

THIS TEXT IS INCLUDED FOR THE INFORMATION OF THE NATIONAL COMMITTEES AND WILL BE DELETED AT THE PUBLICATION STAGE.

FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – PERFORMANCE STANDARD –

Part 121-2: Simplex and duplex cords with single-mode fibre and cylindrical ferrule connectors for category C – Controlled environment

1 Scope

This part of IEC 61753 specifies the test requirements for cords including reference cords used in a controlled (Category C) environment according to IEC 61753-1, where the connectors already comply with the Category C requirements of IEC 61753-1. The tests selected are a subset of the connector tests from IEC 61753-1 appropriate for requalification with additional requirements relevant to cords and the connector/cable interface.

The cords consist of simplex or duplex fibre optic cable terminated at each end of the cable with single-mode fibre optic connector plugs with cylindrical ferrules. The operational wavelength range is between 1 260 nm and 1 625 nm. Short length cords are used as test samples as the attenuation of the cord and the temperature cycling performance will be affected by longer lengths of cable. It is important that any qualification of a cord whose length is greater than 5 m takes these factors into account.

The relevant requirements for the mechanical interface of connector sets are covered by the IEC 61754 all parts. The relevant requirements for the optical interface of connector sets are covered by IEC 61755 (all parts). The relevant requirements for performance of connector sets are covered by IEC 61753 (all parts). The relevant requirements for fibres are covered by IEC 60793-2-50. The relevant requirements for cables for cords are covered by IEC 60794-2-50.

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 60793-2-50, *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*

IEC 60794-2-50, *Optical fibre cables – Part 2-50: Indoor cables – Family specification for simplex and duplex cables for use in terminated cable assemblies*

IEC 60794-2-51, *Optical fibre cables – Part 2-51: Indoor cables – Detail specification for simplex and duplex cables for use in cords for controlled environment*

IEC 61300-1, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 1: General and guidance*

IEC 61300-2-4, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-4: Tests – Fibre/cable retention*

IEC 61300-2-22, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-22: Tests – Change of temperature*

IEC 61300-2-42, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-42: Tests – Static side load for strain relief*

IEC 61300-2-44, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-44: Tests – Flexing of the strain relief of fibre optic devices*

IEC 61300-3-1, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-1: Examinations and measurements – Visual examination*

IEC 61300-3-3, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-3: Examinations and measurements – Active monitoring of changes in attenuation and return loss*

IEC 61300-3-6, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-6: Examinations and measurements – Return loss*

IEC 61300-3-22, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-22: Examinations and measurements – Ferrule compression force*

IEC 61300-3-25, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-25: Examinations and measurements – Concentricity of non-angled ferrules and non-angled ferrules with fibre installed*

IEC 61300-3-26, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-26: Examinations and measurements – Measurement of the angular misalignment between fibre and ferrule axes*

IEC 61300-3-28, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-28: Examinations and measurements – Transient loss*

IEC 61300-3-34, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-34: Examinations and measurements – Attenuation of random mated connectors*

IEC 61300-3-35, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-35: Examinations and measurements – Visual inspection of fibre optic connectors and fibre-stub transceivers*

IEC 61300-3-47, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-47: Examinations and measurements – End face geometry of PC/APC spherically polished ferrules using interferometry*

IEC 61753-1, *Fibre optic interconnecting devices and passive components – Performance standard – Part 1: General and guidance for performance standards*

IEC 61753-021-2, *Fibre optic interconnecting devices and passive components – Performance standard – Part 021-2: Grade C/3 single-mode fibre optic connectors for category C – Controlled environment*

IEC 61754 (all parts), *Fibre optic interconnecting devices and passive components – Fibre optic connector interfaces*

IEC 61755 (all parts), *Fibre optic interconnecting devices and passive components – Connector optical interfaces*

IEC TR 61931, *Fibre optic – Terminology*

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
terminated cable assembly
fibre optic cable terminated with any passive fibre optic component on each end

3.2
cord
cable terminated with fibre optic connectors at each end

EXAMPLE Equipment cord, work area cord or patchcord.

Note 1 to entry: Cord is also referred to as "terminated cable assembly".

[SOURCE: IEC 60794-2-51:2014, 3.2, modify – The definition has been rephrased, and an example and note to entry have been added.]

3.3
connector set
complete assembly of components (plug-adaptor-plug) required to provide demountable coupling between two or more optical fibres

3.4
reference cord
cord terminated with reference connector plugs

3.5
reference connector plug
connector plug manufactured with restricted tolerances for dimensions relevant to lateral and angular offset

Note 1 to entry: See IEC 61755-2-4 and IEC 61755-2-5.

3.6
change in attenuation
peak-to-peak variation

[SOURCE: IEC 61753-021-2:2007, 3.1]

4 Description

4.1 General

Patchcords, work area cords, equipment cords and reference cords (called "cords" in subsequent text) defined according to this document are terminated cable assemblies with optical connector plugs at each end.

The length, unless otherwise specified, is defined as being between the end faces of the connector plugs.

Cords, except reference cords, can be of any cable length. Reference cords have a length between 2 m and 5 m.

4.2 Optical fibres

Optical fibres meeting the requirements of IEC 60793-2-50 category B1.1 and B1.3 single-mode fibres shall be used. Once these cords are qualified, cords with the same construction using B6_a1 and B6_a2 fibre types according to IEC 60793-2-50 are qualified as well.

4.3 Cable design and construction

Cable used for the cords shall conform to the requirements of IEC 60794-2-50 and IEC 60794-2-51.

4.4 Optical connectors

4.4.1 Mechanical connectivity

The dimensional interface requirements in IEC 61754 (all parts) shall be met.

4.4.2 Optical performance requirements

The functionality of the connections according to this document is based upon physical contact. All the connector plugs shall conform to the standard performance grade as defined in IEC 61755 (all parts). Considered attenuation grades are R1 and R2 defined in IEC 61755-2-4 and IEC 61755-2-5, and B, C and D defined in IEC 61755-2-1 and IEC 61755-2-2. Considered return loss grades are 1, 2 and 3 defined in IEC 61755-2-1 and IEC 61755-2-2.

4.4.3 Connector set performance requirements

Connector sets shall conform to the requirements described in IEC 61753-021-2.

4.5 Cable bend radius

Care shall be taken to respect the minimum bend radius of the cable.

5 Tests

5.1 General

All tests and measurements have been selected from IEC 61300 (all parts) for connectors and from the cable test procedure outlined in IEC 60794-1-2. Additional requirements to certain tests are given in Annex C.

5.2 Measurement wavelengths

Unless otherwise specified in the individual test details, all attenuation measurements are made at the wavelengths given in Table 1.

Table 1 – Wavelengths for attenuation and return loss measurements

Fibre type	Centre wavelength nm		
Single-mode	1 310	1 550	1 625

Return loss measurements shall be performed at the wavelengths specified in the individual tests.

5.3 Device under test

For this document, a device under test (DUT) is defined as a terminated cable assembly with optical connector plugs according to IEC 61754 (all parts) at all ends of the cord.

The sample size and product sourcing requirements are defined in Annex A.

The length of the DUT shall be 3,0 m to 5,0 m.

5.4 Test report

A fully documented test report and supporting data shall be prepared and shall be available for inspection as evidence that the tests described in this document have been carried out accordingly.

6 Test procedure

6.1 General

No deviation from the specified test method is allowed.

Unless otherwise specified, all tests shall be carried out at ambient temperature as specified in IEC 61300-1.

6.2 Visual examination

A visual examination shall be carried out on all DUTs before and after all mechanical and environmental tests (see Table 2). The outer cable sheath shall be marked at the end of the connector boot during the initial visual examination (see Annex B).

Table 2 – Visual examination requirements

No.	Test	Requirement	Details	
1	Visual examination	No visible defects of cable or connector plugs	Method: Examination:	IEC 61300-3-1 Product shall be visually checked without magnification

6.3 Fibre optic connector plug end face

The performance of the fibre optic connection depends on characteristics of the end faces of both connector plugs (see Table 3).

Table 3 – End face requirements

No.	Test	Requirement	Details	
2	End face geometry	IEC 61755-3 (all parts)	Method:	IEC 61300-3-47, End face geometry IEC 61300-3-25, Concentricity IEC 61300-3-26, Angular misalignment
3	Fibre optic connector end face visual inspection	IEC 61300-3-35	Method: Examination:	IEC 61300-3-35 Scratches, defects, debris
4	Ferrule compression force[a]	IEC 61754 (all parts): for the connectorised buffered fibre IEC 60794-2-50: additional requirements for the ruggedised fibre cable	Method: Examination:	IEC 61300-3-22 Movement length, compression force

[a] This test is applicable to connector plugs with spring loaded ferrules.

6.4 Optical performance requirements

Optical performance requirements for attenuation and return loss are given in the following Table 4. These requirements are related to connections between the same fibre types.

Table 4 – Optical performance requirements

No.	Test	Requirement	Details	
5	Attenuation	R1 (reference grade):	Method:	IEC 61300-3-34, Method 2
		≤ 0,1 dB	Source type:	LED/LD
		R2 (reference grade):	Wavelength:	(1 310 ± 30) nm
		≤ 0,2 dB		(1 550 ± 30) nm
				(1 625 ± 30) nm
		Grade B:	Source stability:	±0,01 dB over 1 h
		≤ 0,12 dB mean		
		≤ 0,25 dB for 97 %	Detector linearity:	±0,01 dB over the dynamic range to be measured
		Grade C:		
		≤ 0,25 dB mean		
		≤ 0,5 dB for 97 %	Launch fibre length:	> 2 m. Only the fundamental mode shall propagate at the connector interface to be tested and at the detector
		Grade D:		
		≤ 0,5 dB mean	Pre-conditioning procedure:	Clean plug and adaptor according to manufacturer’s instructions
		≤ 1,0 dB for 97 %		
6	Return loss	Grade 1: ≥ 60 dB	Method:	IEC 61300-3-6, Method 1
			Wavelengths:	(1 310 ± 30) nm
		Grade 2: ≥ 45 dB		(1 550 ± 30) nm
				(1 625 ± 30) nm
		Grade 3: ≥ 35 dB	Source stability:	±0,01 dB over 1 h
			Detector linearity:	±0,1 dB over the dynamic range to be measured

6.5 Environmental performance requirements

Environmental performance requirements are given in the following Table 5.

Table 5 – Environmental performance requirements

No.	Test	Requirement	Details	
7	Change of temperature	Change in attenuation during the test at (1 310 ± 30) nm ≤ 0,40 dB at (1 625 ± 30) nm ≤ 1,0 dB Change in attenuation before and after the test at (1 310 ± 30) nm ≤ 0,20 dB at (1 625 ± 30) nm ≤ 0,40 dB Initial and final attenuation shall be ≤ specified for the grade Return loss shall satisfy the requirements for the specified grade Final visual examination: see Annex B	Method: Low temperature: High temperature: Duration at temperature extreme: Rate of change of temperature: Number of cycles: DUT optically functioning: Measurements required: Sampling rate: Attenuation: Return loss: Pre-conditioning procedure: Recovery procedure:	IEC 61300-2-22, see Annex C –10 °C 60 °C 1 h 1 °C/min 5 Yes Measuring procedure: IEC 61300-3-3. Measurements before, during and after the test Max. interval 10 min According to Table 4 According to Table 4 2 h at normal ambient conditions. Clean connector plugs and adaptor according to manufacturer's instructions 2 h at normal ambient conditions. Connection shall not be demated

6.6 Mechanical performance requirements

Mechanical performance requirements are given in the following Table 6.

Table 6 – Mechanical performance requirements

No.	Test	Requirement	Details	
8	Fibre/Cable retention	Change in attenuation during the test at (1 310 ± 30) nm ≤ 0,20 dB at (1 625 ± 30) nm ≤ 0,50 dB Change in attenuation before and after the test at (1 310 ± 30) nm and (1 625 ± 30) nm ≤ 0,20 dB Initial and final attenuation shall be ≤ specified for the grade Return loss shall satisfy the requirements for the specified grade Final visual examination: see Annex B	Method:	IEC 61300-2-4
			Tensile force:	50 N ± 2 N at 5 N/s
			Point of application of the load:	0,3 m from connector plug The connector plug shall be rigidly mounted such that the load is applied to the fibre/cable retention mechanism and not to the coupling mechanism
			Duration of maximum load:	2 min at 50 N
			DUT optically functioning:	Yes
			Measurements required:	Measuring procedure: IEC 61300-3-3. Measurements before, during and after the test
			Sampling rate:	Continuously
			Attenuation:	According to Table 4
			Return loss:	According to Table 4
			Pre-conditioning procedure:	Clean plug and adaptor according to manufacturer's instructions
9	Static side load	Change in attenuation during the test at (1 310 ± 30) nm ≤ 0,20 dB, at (1 625 ± 30) nm ≤ 0,50 dB Change in attenuation before and after the test at (1 310 ± 30) nm and (1 625 ± 30) nm ≤ 0,20 dB Initial and final attenuation shall be ≤ specified for the grade Return loss shall satisfy the requirements for the specified grade Final visual examination: see Annex B	Method:	IEC 61300-2-42
			Magnitude of the load (90° to plug axis):	1 N
			Point of application of the load:	0,2 m from rear of connector plug in two mutually perpendicular directions
			Method of mounting:	An adaptor shall be mounted rigidly to the mounting fixture
			Duration of load:	1 h
			DUT optically functioning:	Yes
			Measurements required:	Measuring procedure: IEC 61300-3-3. Measurements before, during and after the test
			Sampling rate:	Continuously
			Attenuation:	According to Table 4
			Return loss:	According to Table 4
			Pre-conditioning procedure:	Clean plug and adaptor according to manufacturer's instructions

No.	Test	Requirement	Details	
10	Flexing strain relief of fibre optic devices	Change in attenuation during the test at (1 310 ± 30) nm ≤ 0,20 dB, at (1 550 ± 30) nm ≤ 0,30 dB at (1 625 ± 30) nm ≤ 0,50 dB Change in attenuation before and after the test at (1 310 ± 30) nm, (1 550 ± 30) nm and (1 625 ± 30) nm ≤ 0,20 dB Initial and final attenuation shall be ≤ specified for the grade Return loss shall satisfy the requirements for the specified grade Final visual examination: see Annex B	Method: Magnitude of the load: Point of application of the load: Method of mounting: Cycle: Number of cycles: Cycling rate: DUT optically functioning: Measurements required: Sampling rate: Attenuation: Return loss: Pre-conditioning procedure:	IEC 61300-2-44 2 N 0,2 m from rear of connector plug An adaptor shall be mounted rigidly to the mounting fixture From 0° to –90° to 0° to +90° to 0° 100 20 cycles/min Yes Measuring procedure: IEC 61300-3-28. Measurements before, during and after the test Continuously According to Table 4 According to Table 4 Clean plug and adaptor according to manufacturer's instructions

Annex A
(normative)

Sample size requirements

Sample size for the cords shall be as indicated in the following Table A.1.

Table A.1 – Sample size requirements

No.	Test	Simplex	Duplex
1	Visual examination	15	10
2	End face geometry	15	10
3	Fibre optic cylindrical connector plug end face visual inspection	15	10
4	Ferrule compression force	15	10
5	Attenuation	15	10
6	Return loss	15	10
7	Change of temperature	6	3
8	Fibre/cable retention	6	3
10	Static side load	6	3
11	Flexing strain relief of fibre optic devices	6	3

The above tests are not intended to be performed in any particular sequence or grouping. They are intended to be performed individually; however, products from previous tests may be used if desired.

Annex B
(normative)

Visual examination of outer cable sheath movement

B.1 Scope

This visual examination shall be made to ensure that the captivation or attachment of a cable sheath to a connector plug will withstand all environmental and mechanical tests required in this document.

B.2 Preparation of the DUT and initial visual examination

Preparation shall be made after initial visual examination (before all subsequent tests).

Mark the outer cable sheath at the end of the connector boot at both ends of the cable assembly as indicated in Figure B.1. The marks are required to identify movement of the cable sheath caused by environmental and mechanical stresses during subsequent tests.

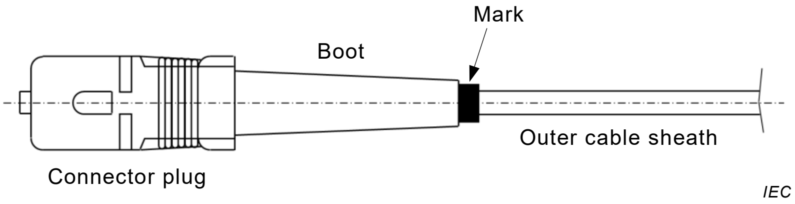

Figure B.1 – Initial marking of the cable sheath

If the connector plug has a shrink-tube as part of the boot as, for example in some types of LC connector plugs, the mark shall be made on the outer cable sheath right at the end of the shrink-tube.

B.3 Final visual examination of outer cable sheath movement

Final visual examination shall be made after all tests have been finished. The outer sheath movement is visible through the movements of the marks at the outer cable sheath (see Figure B.2).

Requirements:

The allowed movement of the outer cable sheath relative to the connector boots (at least of its fixing point e.g. sheath crimp, shrink-tube or gluing) shall be 1 mm maximum at any connector plug.

Dimension in millimetre

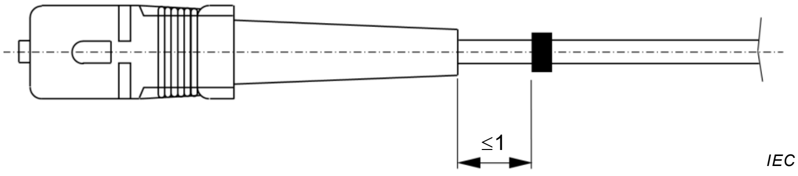

Figure B.2 – Final visual examination

NOTE The SC connector in the Figures B.1 and B.2 is assumed as an example.

Annex C
(normative)

Change of temperature

The additional requirements for the change of temperature test (see configuration in Figure C.1) shall be as follows.

- The whole length of the patchcord together with both connections shall be within the climatic chamber.
- The cable coils shall be free, without any cable reel, and supported horizontally in the climatic chamber. The winding radius shall be larger than 150 mm.

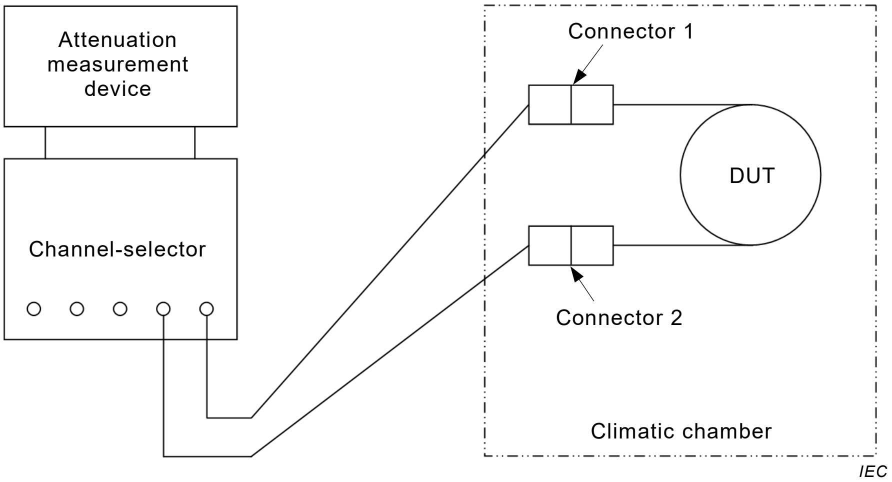

Figure C.1 – Change of temperature test configuration

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