PD IEC/TR 61282-14:2016

Incorporating corrigendum April 2016

BSI Standards Publication

Fibre optic communication system design guides

Part 14: Determination of the uncertainties of attenuation measurements in fibre plants

bsi.

National foreword

This Published Document is the UK implementation of IEC/TR 61282-14:2016, incorporating corrigendum April 2016.

The UK participation in its preparation was entrusted by Technical Committee GEL/86, Fibre optics, to Subcommittee GEL/86/3, Fibre optic systems and active devices.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2016

ISBN 978 0 580 94415 4
ICS 33.180.01

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 January 2016.

Amendments/corrigenda issued since publication

Date	Text affected
31 May 2016	Implementation of IEC corrigendum April 2016: Table C.1 updated

IEC TR 61282-14

Edition 1.0 2016-01

TECHNICAL REPORT

colour inside

Fibre optic communication system design guides –
Part 14: Determination of the uncertainties of attenuation measurements in fibre plants

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.180.01

ISBN 978-2-8322-3111-1

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 14: Determination of the uncertainties of attenuation measurements in fibre plants

FOREWORD

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 61282-14, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

This publication contains an attached file titled, “Supplemental Data for Section 8”, in the form of an Excel spread sheet. This file is intended to be used as a complement and does not form an integral part of the standard.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86C/1339/DTR	86C/1351/RVC

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

A list of all parts in the IEC 61282 series, published under the general title *Fibre-optic communication system design guides*, can be found on the IEC website.

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 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

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

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

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

The determination of the uncertainty of every measurement is a key activity, which should be performed by applying dedicated methods as extensively presented in reference documents such as ISO/IEC Guide 98-3:2008, Guide to the uncertainty of measurement (GUM).

This Technical Report shows a practical application of these methods for the determination of the measurement uncertainty of the attenuation of fibre optic cabling using optical light sources and power meters as defined in IEC 61280-4-1 and IEC 61280-4-2.

It includes the review of all contributing factors to uncertainty (such as launch conditions, spectral width, stability of source, power meter polarization, resolution, linearity, quality of test cord reference connectors, etc.) to determine the overall measurement uncertainty. The Technical Report applies to the measurement of single mode or multimode fibres without restrictions to the fibre parameters, including mode field diameter, core diameter and numerical aperture. However, numerical values given in Clause C.2 and typical values given in Annex D are not valid for multimode fibres types A2, A3 and A4.

The list of uncertainties presented in this Technical Report is related to this particular application and should be reconsidered if measurement conditions are not compliant to measurement requirements defined by IEC 61280-4-1 and 61280-4-2.

The reference document for general uncertainty calculations is ISO/IEC Guide 98-3:2008, and this report does not intend to replace it; it only represents an example and should be used in conjunction with ISO/IEC Guide 98-3:2008. A brief introduction to the determination of measurement uncertainty according to ISO/IEC Guide 98-3:2008 is given in Annex A.

This Technical Report is associated with a calculation spreadsheet (Excel) containing practical calculations.

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 14: Determination of the uncertainties of attenuation measurements in fibre plants

1 Scope

This part of IEC 61282, which is a Technical Report, establishes the detailed analysis and calculation of the uncertainties related to the measurement of the attenuation of both multimode and single mode optical fibre cabling using optical light sources and power meters.

2 Normative references

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

IEC 61280-4-1:2009, *Fibre-optic communication subsystem test procedures – Part 4-1: Installed cable plant – Multimode attenuation measurement*

IEC 61280-4-2:2014, *Fibre-optic communication subsystem test procedures – Part 4-2: Installed cable plant – Single-mode attenuation and optical return loss measurement*

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

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
attenuation
$\boldsymbol{L}$
reduction of optical power induced by transmission through a medium such as cabling, given as L (dB)

$$L_{\mathrm{dB}} = 10 \log_{10}(P_{\mathrm{in}}/P_{\mathrm{out}})$$

where P_{in} and P_{out} are the power, typically measured in mW, into and out of the cabling

3.1.2
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 standards

3.1.3
encircled flux
EF
fraction of the radial-weighted cumulative near field power to the total radial-weighted output power as a function of radial distance from the optical centre of the core

3.1.4
measurement repeatability
measurement precision under a set of repeatability conditions of measurement

3.1.5
measurement reproducibility
reproducibility
measurement precision under reproducibility conditions of measurement

3.1.6
polarization dependent loss
PDL
maximum variation of insertion loss due to a variation of the state of polarization (SOP) over all the SOPs

3.1.7
nonlinearity
NL
for a power meter, the relative difference between the *response* at a given power P and the response at a reference power P_0:

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

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

3.1.8
uncertainty of measurement
quantified doubt about the result of a measurement

3.1.9
stability
ability of a measuring instrument to keep its performance characteristics within a specified range during a specified time interval, all other conditions being the same

3.1.10
repeatability condition
condition of measurement that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicates measurements on the same or similar objects over a short period of time

3.1.11
reproducibility condition
condition of measurement that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects

3.1.12
standard uncertainty
u
uncertainty of a measurement result expressed as a standard deviation

Note 1 to entry: For further information, see ISO/IEC Guide 98-3.

3.1.13
uncertainty type A
type of uncertainty obtained by a statistical analysis of a series of observations, such as when evaluating certain random effects of measurement

Note 1 to entry: See Annex A and ISO/IEC Guide 98-3.

3.1.14
uncertainty type B
type of uncertainty obtained by means other than a statistical analysis of observations, for example an estimation of probable sources of uncertainty, such as when evaluating systematic effects of measurement

Note 1 to entry: See Annex A and ISO/IEC Guide 98-3.

3.2 Abbreviations

For the purposes of this document, the following acronyms apply.

APC	angled physical contact (description of connector style)
CW	continuous wave
LSPM	light source power meter
OPM	optical power meter
PC	physical contact (description of connector style that is not angled)

4 Overview of uncertainty

4.1 What is uncertainty?

According to ISO/IEC Guide 98-3:2008 (GUM), the uncertainty of a measurement is the quantified doubt that exists about the result of any measurement. For every measurement, even the most careful, there is always a margin of doubt.

For example, when measuring the attenuation of fibre optic cabling, the operator may observe a variation of the displayed power level on the power meter and be unable to know which value should be recorded. This variation of the displayed value is an element of doubt regarding the result of the measurement.

4.2 Origin of uncertainties

Uncertainties come from: measurement devices, the item to be measured, the measurement process, operator skills, references used, and the environment.

4.3 What may not be considered as uncertainty?

Unknown parameters that contribute directly or indirectly to the quantity to be measured cannot be considered as uncertainties. For example, when measuring a cabling, mode field diameter or numerical aperture of different fibres of cabling are unknown; however, mismatch of these parameters cause the measured attenuation.

Also, poor knowledge of measurement conditions generates uncertainties but is not directly an uncertainty. A common example is the wavelength of the optical source: If the wavelength of the source is known with an uncertainty smaller than 1 nm, the measurement condition can be specified precisely. Conversely, if the wavelength of the source is known to be within a range of 40 nm, the possible variation of the attenuation of the device under test should be estimated based on the typical variation of attenuation over the wavelength range for a given length of fibre.

5 Fibre cabling attenuation measurement

5.1 Measurement methods

Three attenuation measurement methods use an optical light source and power meter (LSPM) to measure input and output power levels of the cabling under test to determine the attenuation. These measurement methods are designated respectively, one-cord, three-cord and two-cord reference method.

The main functional difference between these methods is the way the input power level, known as the reference power level (P_{in}), is measured (see Annex B).

Refer to IEC 61280-4-1 and 61280-4-2 for more details.

NOTE Measurement methods presented in ISO/IEC 14763-3 have different names and are slightly different. See Clause B.2.

5.2 Sources of uncertainty to be considered

5.2.1 Analysis

An extensive analysis of the source of uncertainties to be considered has been conducted. This resulted in the sorted source of uncertainty given in Table 1.

Table 1 – Source of uncertainty (raw list)

Source of uncertainty	Type of origin	Index
Measurement source instability (power deviation over time)	Measurement devices	01
Source wavelength	Measurement devices	02
Source spectrum (spectral width)	Measurement devices	03
Laser speckle	Measurement devices	04
Launch condition for multimode fibres (dependent upon the compliance or noncompliance with the EF template and a function of the attenuation of the measured cabling)	Measurement devices	05
Power meter non linearity	Measurement devices	06
Power meter reading resolution	Measurement devices	07
Power meter spatial uniformity	References used	08
Power meter polarization sensitivity	Measurement devices	09
Power meter noise	Measurement devices	10
Power meter stability	Measurement devices	11
Power meter calibration	References used	12
Reference connector / fibre attenuation uncertainty	References used	13
Connector mating repeatability (Reference or cabling)	References used/ item to be measured	14
Connector PDL	References used / item to be measured	15
Reflections (FP cavity)	References used / item to be measured	16
Connector end face cleanliness	Operator skills	17
Fibre handling	Operator skills	18
Calculation errors	Measurement process	19
Numerical aperture of the fibre	Item to be measured	20
Core diameter of the fibre or mode filed diameter	Item to be measured	21
Fibre non linearity	Item to be measured	22
Temperature	Environment	23
Humidity	Environment	24

Some of the uncertainties listed in Table 1 are negligible or need to be grouped together to be estimated; however, some of them apply to different domains. Figure 1 presents an organised list of these uncertainties.

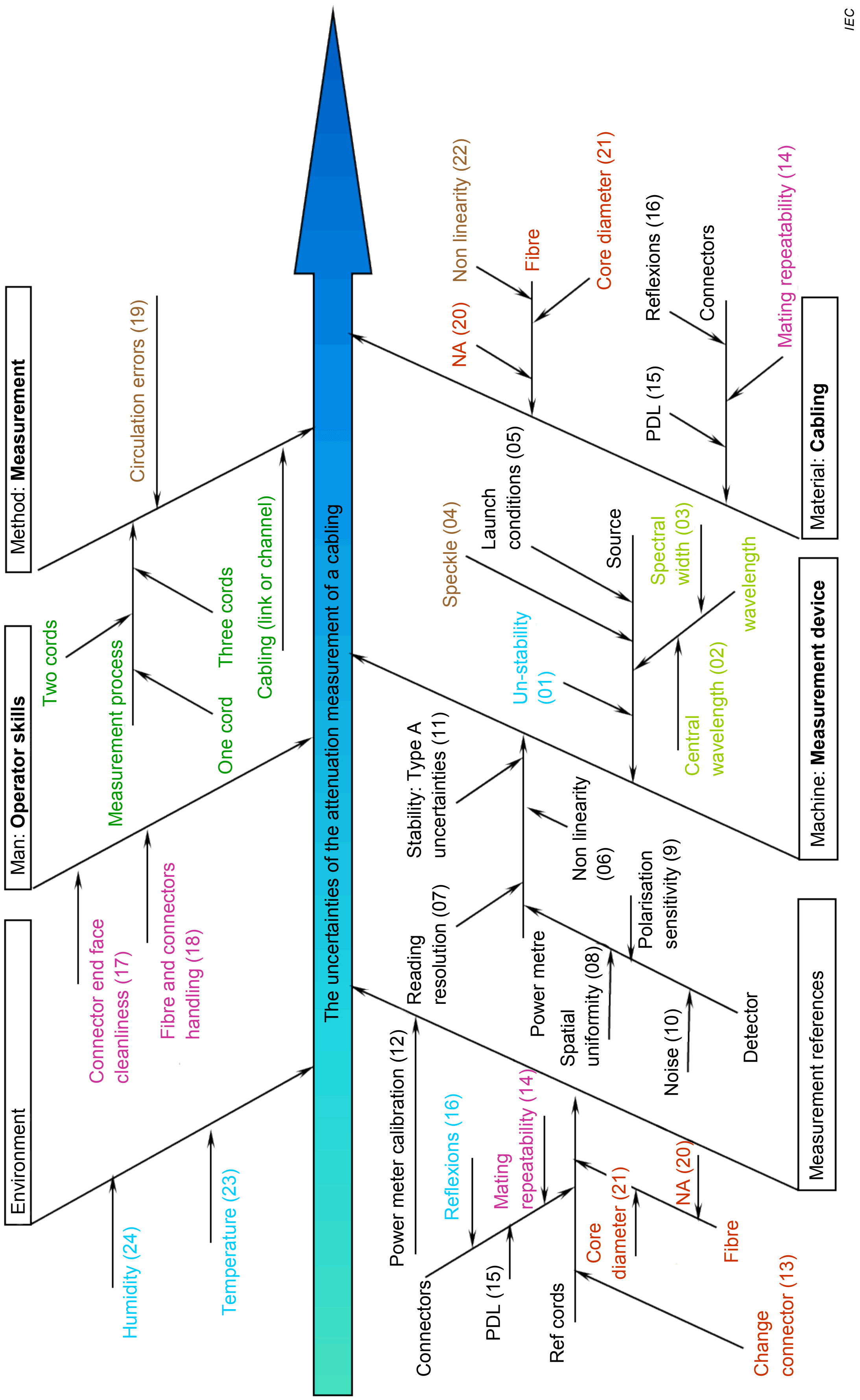


Figure 1 – Fish bone analysis

5.2.2 Uncertainties due to the environment

It is assumed that environmental parameters (temperature and humidity) generate negligible variations of the attenuation of the fibre and that fibre environmental conditions are reported as measurement conditions.

Temperature and humidity can generate source and power meter instability. This instability shall be reported in 5.2.5 (see also C.1.2).

NOTE This corresponds to uncertainties reported as index 23 and 24.

5.2.3 Uncertainties due to operator skills

It is assumed that operators follow approved procedures for connector end face inspection and cleaning, so the connector attenuation is as expected.

It is also assumed that operator skills do not create additional variations to those included with connector mating repeatability.

NOTE This corresponds to uncertainties reported as index 17 and 18.

5.2.4 Uncertainties due to measurement methods

Measurement methods do not affect the uncertainties directly, as different numbers of connectors are used depending on the method used. The accumulation of uncertainties takes into account the correct amount of uncertainties related to the connectors.

Calculation errors due to truncation of results may exist in this type of measurement, especially if measurements are controlled by an external computer. However, most of the time, users simply calculate the attenuation by an embedded dBr (decibel relative) function that can be assumed to have no more error than the rounding error of the optical power meter (see 5.2.5).

NOTE This corresponds to uncertainty reported as index 19.

5.2.5 Uncertainties due to measuring instruments

Table 2 provides a list of the uncertainties to be taken into account for the measurement devices group.

Table 2 – Uncertainties due to measuring instruments

Reference / Symbol	Index	Description	Concerned element	Apply to P_{in}	Apply to P_{out}	Other condition
5.2.5.1 $u_{P\text{stab}}$	01	Relative uncertainty arising from the instability of the optical source and any other instabilities (assumed to include instability due to multiple reflections)	Source	Yes	Yes	
5.2.5.2 $u_{\lambda \text{s}}$	02	Relative attenuation uncertainty arising from the uncertainty of the optical source wavelength. See C.2.4 and C.2.5	Source	No	Yes	If unknown
5.2.5.3 u_{MMLC}	05	Relative uncertainty due to the multimode launch condition; See C.2.6	Source and cabling	No	Yes	MM
5.2.5.4 u_{Lin}	06	Relative uncertainty arising from the non-linearity of the power meter. This contribution will only be considered when using the same power meter for the measurement of P_{in} and of P_{out}.	Power meter	No	Yes	One power meter
5.2.5.5 $u_{\text{Displ}\ i}$	07	Relative uncertainty arising from the finite display resolution of power meter i	Power meter	Yes	Yes	
5.2.5.6 $u_{P\text{space}}$	08	Relative uncertainty arising from power meter spatial uniformity. Only significant for single mode measurement and when using a different type of connector for P_{in} and of P_{out} and using the same power meter for the measurement of P_{in} and P_{out}.	Power meter	Yes	Yes	If APC and PC connectors are used. One power meter
5.2.5.7 $u_{\text{PDR}\ i}$	09	Relative uncertainty arising from the polarization dependency of power meter i (see C.2.7)	Power meter	Yes	Yes	SM
5.2.5.8 $u_{P\text{noise}}$	10	Relative uncertainty arising from power meter noise Becomes negligible if power level remains 30 dB over the power meter noise level (see C.2.2)	Power meter	Yes	Yes	
5.2.5.9 $u_{\text{PM stabin}}$ $u_{\text{PM stabout}}$	11	Relative uncertainty arising from power meter instability (see C.2.3)	Power meter	Yes	Yes	
5.2.5.10 $u_{\text{abs}\ P_{in}}$ $u_{\text{abs}\ P_{out}}$	12	Relative uncertainties of the absolute power measurements of P_{in} and of P_{out}. These uncertainties need to be considered only when performing measurements of P_{in} and P_{out} using two different power meters. The use of two different power meters is not recommended (see also C.2.8)	Power meter	Yes	Yes	If two different power meters are used

When measuring fibre optic cabling, and assuming the spectrum of the sources used is symmetrical, the variation of the spectral width does not cause variation of the attenuation of the cabling. Hence, uncertainties due to the spectral width are assumed to be negligible.

NOTE This corresponds to uncertainty reported as index 03.

The speckle due to a laser source used to measure a multimode cabling may affect the stability of the power meter measurements. However, this would occur only if the power meter detector is not spatially uniform; hence uncertainties due to laser source speckle are assumed to be negligible.

NOTE This corresponds to uncertainty reported as index 04.

5.2.6 Uncertainties due to the setup

Table 3 provides a list of the uncertainties to be taken into account for the setup group.

Table 3 – Uncertainties due to the setup

Reference / Symbol	Index	Description	Concerned element	Apply to P_{in}	Apply to P_{out}	Other condition
5.2.6.1 $u_{Mreprod}$	13	Mating reproducibility (setup)	Ref cords	Yes	No	
5.2.6.2 u_{Mating}	14	Relative uncertainty related to the repeatability of the reference connector mating	Ref cords	Yes	No	Dependent upon the method used
5.2.6.3 u_{CPDL}	15	Relative uncertainty related to the PDL of the reference APC connectors	Ref cords	Yes	Yes	SM and APC

Mismatch of reference cord fibre parameters like core diameter (or mode field diameter) and numerical aperture may generate variation of the connector attenuation. Uncertainty due to reference cord fibre parameters is assumed to be included in the relative uncertainty of the attenuation of the reference connectors.

NOTE 1 This corresponds to uncertainties reported as index 20 and 21.

Reflections may exist between the optical input port of the power meter and the cabling connector. Multiple reflections may exist in all optical connectors causing variation of the source and/or higher loss. Uncertainty due to multiple reflections is assumed to be included in the relative stability of the source and in the attenuation of the reference connectors.

NOTE 2 This corresponds to uncertainty reported as index 16.

5.2.7 Uncertainties due to cabling

Table 4 provides the list of the uncertainties to be taken into account for the cabling group.

Table 4 – Uncertainties due to cabling

Reference	Index	Description	Concerned element	Apply to P_{in}	Apply to P_{out}	Other condition
5.2.7.1 $u_{Mreproduc}$	13	Mating reproducibility (cabling)	Ref cords	No	Yes	
5.2.7.2 u_{Mating}	14	Relative uncertainty related to the repeatability of the reference connector mating to cabling connectors	Cabling	No	Yes	Quantity of connectors depends on method used.
5.2.7.3 u_{CPDL}	15	Relative uncertainty related to the PDL of the cabling APC connectors	Cabling	No	Yes	SM and APC

Mismatch of reference cord fibre parameters such as core diameter (or mode field diameter) and numerical aperture may generate variation of the connector attenuation. Uncertainty due to reference cord fibre parameters is assumed to be included in the relative uncertainty of the attenuation of the reference connectors.

NOTE 1 This corresponds to uncertainties reported as index 20 and 21.

Fibre cabling non-linearities such as Raman scattering or Brillouin scattering should be considered if a high power source is used. However, when using common sources having a maximum output power lower than 1 mW (0 dBm), fibre cabling non linearity is negligible.

NOTE 2 This corresponds to uncertainty reported as index 22.

6 Uncertainties estimation

6.1 Measurement model

The attenuation L is expressed as the ratio of the input power to the output power level of the cabling under test as shown in Figure 2.

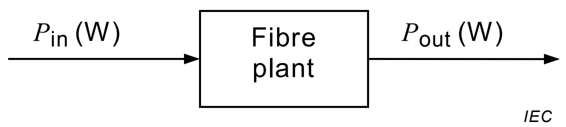


Figure 2 – Measurement model

$$L_{dB} = 10 \cdot \log_{10}(P_{in} / P_{out}) \quad (1)$$

where

P_{in} is the input power

P_{out} is the output power

$$L = P_{in} / P_{out} \quad (2)$$

The relative uncertainty of the power ratio is calculated according to Formula 13 of ISO/IEC Guide 98-3:2008 as follows:

$$u_L^2 = \sum_{i=1}^{N} \left(\frac{\partial L}{\partial P_i} \right)^2 \cdot u_{P_i}^2 + 2 \cdot \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{\partial L}{\partial P_i} \cdot \frac{\partial L}{\partial Pj} \cdot u(P_i, P_j) \quad (3)$$

where

u_{Pi} are the uncertainties related to the measurements of power levels, and

P_i, and $u(P_i,P_j)$ are the covariance.

For the purposes of this Technical Report, it is supposed that uncertainties that may be correlated, like the stability of the source and the effect of multiple reflections, were grouped together.

This does not apply to P_{in} and P_{out} when read from a single power meter. To avoid analysis of the covariance of these two strongly correlated readings, the following measurement model is used:

$$P_{\text{in}} = k_{\text{c}} P_{\text{in-read}}$$
$$P_{\text{out}} = k_{\text{c}} k_{\text{lin}} P_{\text{out-read}} \tag{4}$$

- where
- k_{c} is the power meter calibration factor, and
- k_{lin} is the deviation created on P_{out} by the non-linearity.

Applying this model to the attenuation measurement L shows that the calibration factor should not be taken into account, while the non-linearity shall be considered for P_{out} only.

$$L_{\text{in}} = \frac{k_{\text{c}} P_{\text{in-read}}}{k_{\text{c}} k_{\text{lin}} P_{\text{out-read}}} = \frac{P_{\text{in-read}}}{k_{\text{lin}} P_{\text{out-read}}} \tag{5}$$

Therefore, Equation (3) yields the following simplified equation:

$$u_L{}^2 = \sum_{i=1}^{N} \left(\frac{\partial L}{\partial P_i} \right)^2 \cdot u_{P_i}{}^2 \tag{6}$$

By calculating the partial derivatives using the previous equation, one gets:

$$u_L{}^2 = \sum_{i=1}^{N} \left(\frac{\partial L}{\partial P_i} \right)^2 \cdot u_{P_i}{}^2 = \left(\frac{\partial L}{\partial P_{\text{in}}} \right)^2 \cdot u_{P_{\text{in}}}{}^2 + \left(\frac{\partial L}{\partial P_{\text{out}}} \right)^2 \cdot u_{P_{\text{out}}}{}^2 = \left(\frac{1}{P_{\text{out}}} \right)^2 \cdot u_{P_{\text{in}}}{}^2 + \left(\frac{-P_{\text{in}}}{P_{\text{out}}{}^2} \right)^2 \cdot u_{P_{\text{out}}}{}^2 \tag{7}$$

It is common to express the uncertainties $u_{P_{\text{in}}}$ and $u_{P_{\text{out}}}$ in a relative form, namely:

$u_{n\,P_{\text{in}}} = u_{P_{\text{in}}} / P_{\text{in}}$ and $u_{n\,P_{\text{out}}} = u_{P_{\text{out}}} / P_{\text{out}}$.

This can be achieved by dividing Equation (7) by L^2, namely:

$$\left(\frac{u_L}{L} \right)^2 = \left(\frac{P_{\text{out}}}{P_{\text{in}}} \right)^2 \cdot \left(\frac{1}{P_{\text{out}}} \right)^2 \cdot u_{P_{\text{in}}}{}^2 + \left(\frac{P_{\text{out}}}{P_{\text{in}}} \right)^2 \cdot \left(\frac{-P_{\text{in}}}{P_{\text{out}}{}^2} \right)^2 \cdot u_{P_{\text{out}}}{}^2 = \left(\frac{u_{P_{\text{in}}}}{P_{\text{in}}} \right)^2 + \left(\frac{u_{P_{\text{out}}}}{P_{\text{out}}} \right)^2 \tag{8}$$

This can be finally written as:

$$\left(\frac{u_L}{L} \right)^2 = u_{n\,P_{\text{in}}}{}^2 + u_{n\,P_{\text{out}}}{}^2 \tag{9}$$

6.2 Accumulation of uncertainties

The relative uncertainties $u_{n\,P_{\text{in}}}$ and $u_{n\,P_{\text{out}}}$ can be expressed as the accumulation of the previously defined relative uncertainties.

As there are many possible measurement configurations, the accumulation of uncertainties can only be analytically presented for a particular example. The calculation reported below applies to the measurement of a single mode link having PC connectors, using the one cord method with a single power meter and a single set of reference cables.

NOTE Calculation results for the other configurations are provided in Table 6.

$$u_{\mathrm{n}\,P_{\mathrm{in}}} = \sqrt{u_{P_{\mathrm{stabin}}}{}^2 + u_{\mathrm{Displ_{in}}}{}^2 + u_{\mathrm{PDR_{in}}}{}^2 + u_{\mathrm{Pnoisein}}{}^2 + u_{\mathrm{PM_{stabin}}}{}^2 + u_{\mathrm{Mreprodin}}{}^2 + u_{\mathrm{Matingin}}{}^2} \quad (10)$$

$$u_{\mathrm{n}\,P_{\mathrm{out}}} = \sqrt{\begin{aligned}&u_{P_{\mathrm{stabout}}}{}^2 + u_{\lambda\mathrm{s}}{}^2 + u_{\mathrm{Lin}}{}^2 + u_{\mathrm{Displ_{out}}}{}^2 + u_{\mathrm{PDR_{out}}}{}^2 + u_{\mathrm{Pnoiseout}}{}^2 + u_{\mathrm{PM_{stabout}}}{}^2\\ &+ u_{\mathrm{Mreprodout}}{}^2 + u_{\mathrm{Matingout}}{}^2\end{aligned}} \quad (11)$$

This leads to the following formula:

$$\frac{u_{\mathrm{L}}}{L} = \sqrt{\begin{aligned}&u_{P_{\mathrm{stabin}}}{}^2 + u_{\mathrm{Displ_{in}}}{}^2 + u_{\mathrm{PDR}_{in}}{}^2 + u_{\mathrm{Pnoisein}}{}^2 + u_{\mathrm{PM_{stabin}}}{}^2 + u_{\mathrm{Mreprodin}}{}^2 + u_{\mathrm{Matingin}}{}^2 + u_{P_{\mathrm{stabout}}}{}^2 + u_{\lambda\mathrm{s}}{}^2\\ &+ u_{\mathrm{Lin}}{}^2 + u_{\mathrm{Displ_{out}}}{}^2 + u_{\mathrm{PDR_{out}}}{}^2 + u_{\mathrm{Pnoiseout}}{}^2 + u_{\mathrm{PM_{stabout}}}{}^2 + u_{\mathrm{Mreprodout}}{}^2 + u_{\mathrm{Matingout}}{}^2\end{aligned}} \quad (12)$$

Assuming the P_{in} and P_{out} related terms are equal, grouping the terms gets:

$$\frac{u_{\mathrm{L}}}{L} = \sqrt{2u_{P_{\mathrm{stab}}}{}^2 + 2u_{\mathrm{Displ}}{}^2 + 2u_{\mathrm{PDR}}{}^2 + 2u_{\mathrm{Pnoise}}{}^2 + 2u_{\mathrm{PM_{stab}}}{}^2 + 2u_{\mathrm{M_{reprod}}}{}^2 + 2u_{\mathrm{Mating}}{}^2 + u_{\lambda\mathrm{s}}{}^2 + u_{\mathrm{Lin}}{}^2} \quad (13)$$

The combined expanded uncertainty will finally be given by:

$$\frac{U_{\mathrm{L}}}{L} = k \cdot \frac{u_{\mathrm{L}}}{L} \quad (14)$$

where k is the coverage factor.

If needed, the logarithmic value of the uncertainty will finally be calculated using the simplified conversion method (see Annex E):

$$\left(\frac{U_{\mathrm{L}}}{L}\right)_{\mathrm{dB}} = \frac{10}{\ln(10)} \frac{U_{\mathrm{L}}}{L} \quad (15)$$

7 General representation of the equation using sensitivity coefficients

Equation 13 can be expressed using the following general form:

$$\left(\frac{u_{\mathrm{L}}}{L}\right)^2 = \sum_{i=1}^{N}\left[c_i{}^2 \cdot u_{n_i}{}^2\right] \quad (16)$$

where $c_i{}^2$ represent the coefficients of Equation 13, hereafter called sensitivity coefficients.

Table 5 reports the value of the sensitivity coefficients c_i for different measurement conditions as defined by IEC 61280-4-1 and 61280-4-2.

Table 6 reports the value of the sensitivity coefficients c_i for measurement conditions defined in ISO/IEC 14763-3:2014.

NOTE As in Equation (13), it is assumed that P_{in} and P_{out} related terms are equal.

Table 5 – Sensitivity coefficients for IEC 61280-4-1 and IEC 61280-4-2 methods

Source / Sensitivity coefficients		Single mode			Multimode		
Reference	**Name**	**1-cord**	**3-cord**	**2-cord**	**1-cord**	**3-cord**	**2-cord**
5.2.5.1	Instability of the optical source	1,414	1,414	1,414	1,414	1,414	1,414
5.2.5.2	Relative uncertainty arising from the uncertainty of the optical source wavelength	**1**	**1**	**1**	**1**	**1**	**1**
5.2.5.3	Relative uncertainty due to multimode launch condition	0	0	0	**1**	**1**	**1**
5.2.5.4	Relative uncertainty due to non-linearity of the power meter[a)]	1	1	1	1	1	1
5.2.5.5	Relative uncertainty due to finite display resolution of power meter	1,414	1,414	1,414	1,414	1,414	1,414
5.2.5.6	Relative uncertainty due to power meter spatial uniformity[b)]	1,414	1,414	1,414	0	0	0
5.2.5.7	Relative uncertainty due to polarization dependency of power meter	1,414	1,414	1,414	0	0	0
5.2.5.8	Relative uncertainty due to power meter noise	**1,414**	**1,414**	**1,414**	**1,414**	**1,414**	**1,414**
5.2.5.9	Relative uncertainty arising from power meter instability	1,414	1,414	1,414	1,414	1,414	1,414
5.2.5.10	Relative uncertainties of the absolute power measurements[c)]	1,414	1,414	1,414	1,414	1,414	1,414
5.2.6.1	Mating reproducibility (setup)	0	1,414	1	0	1,414	1
5.2.6.2	Repeatability of the reference connectors mating	0	1,414	1	0	1,414	1
5.2.6.3	PDL of the reference APC connectors[d)]	1	1,732	1,414	0	0	0
5.2.7.1	Mating reproducibility (cabling)	1,414	1,414	1,414	1,414	1,414	1,414
5.2.7.2	Relative uncertainty related to the repeatability of the reference connector mating to cabling connectors	1,414	1,414	1,414	1,414	1,414	1,414
5.2.7.3	Relative uncertainty related to the PDL of the cabling APC connectors[d)]	1,732	1,732	1,732	0	0	0

NOTE Values in blue characters depend on the associated note. Values in **bold** characters denote uncertainties that depend on other parameters (see Annex C).

a) Only when using only one power meter. The coefficient shall be equal to zero if two different power meters are used.

b) Only when using both PC and APC connectors. The coefficient shall be equal to zero if the same type of connector is used.

c) Only when using two different power meters. The coefficient shall be equal to zero if only one power meter is used.

d) Only when using APC connectors. The coefficient shall be equal to zero when PC connectors are used.

Table 6 – Sensitivity coefficients for ISO/IEC 14763-3:2014 methods

Source / Sensitivity coefficients		Single mode		Multimode	
Reference	**Name**	**Channels**	**Links**	**Channels**	**Links**
5.2.5.1	Instability of the optical source	1,414	1,414	1,414	1,414
5.2.5.2	Relative uncertainty arising from the uncertainty of the optical source wavelength	**1**	**1**	**1**	**1**
5.2.5.3	Relative uncertainty due to multimode launch condition	0	0	**1**	**1**
5.2.5.4	Relative uncertainty due to non-linearity of the power meter[a)]	1	1	1	1
5.2.5.5	Relative uncertainty due to finite display resolution of power meter	1,414	1,414	1,414	1,414
5.2.5.6	Relative uncertainty due to power meter spatial uniformity[b)]	1,414	1,414	0	0
5.2.5.7	Relative uncertainty due to polarization dependency of power meter	1,414	1,414	0	0
5.2.5.8	Relative uncertainty due to power meter noise	**1,414**	**1,414**	**1,414**	**1,414**
5.2.5.9	Relative uncertainty arising from power meter instability	1,414	1,414	1,414	1,414
5.2.5.10	Relative uncertainties of the absolute power measurements[c)]	1,414	1,414	1,414	1,414
5.2.6.1	Mating reproducibility	0	0	0	0
5.2.6.2	Repeatability of the reference connectors mating	0	0	0	0
5.2.6.3	PDL of the reference APC connectors[d)]	1	1	0	0
5.2.7.1	Mating reproducibility (cabling)	0	1,414	0	1,414
5.2.7.2	Relative uncertainty related to the repeatability of the reference connector mating to cabling connectors	0	1,414	0	1,414
5.2.7.3	Relative uncertainty related to the PDL of the cabling APC connectors[d)]	1,732	1,732	0	0

NOTE Values in blue characters depend on the associated note. Values in **bold** characters denote uncertainties that depend on other parameters (see Annex C).

a) Only when using only one power meter. The coefficient shall be equal to zero if two different power meters are used.

b) Only when using both PC and APC connectors. The coefficient shall be equal to zero if the same type of connector is used.

c) Only when using two different power meters. The coefficient shall be equal to zero if only one power meter is used.

d) Only when using APC connectors. The coefficient shall be equal to zero when PC connectors are used.

8 Calculation

8.1 Combined standard uncertainty

Determine the individual uncertainties contributions reported in Table 2, Table 3 and Table 4 using measurement device supplier data and Annex C.

Combine individual uncertainties contributions using Equation 16 and Table 5 or Table 6, to determine $\frac{u_\mathrm{L}}{L}$.

8.2 Expanded uncertainty

Calculate the expanded uncertainty from:

$$\frac{U_\mathrm{L}}{L} = k \times \frac{u_\mathrm{L}}{L} \tag{17}$$

where k is the coverage factor.

8.3 Determination of the coverage factor *k*

8.3.1 General approach

Usually, the level of confidence for reporting is chosen to 95 % as a default value, and hence the associated value of k is 2 (see Annex A for more details).

8.3.2 Discussion

The statement in 8.3.1 is only valid if the effective degree of freedom ν_eff is large (e.g. >50), which is true most of the time. However, ν_eff, could be lower in some cases, especially when a significant contribution is not well known.

The effective degree of freedom ν_eff, can be calculated from ISO/IEC 98-3:2008 equation G.2b:

$$\nu_\mathrm{eff} = \frac{u_L^4}{\sum_{i=1}^{n} \frac{c_i u_i^4}{\nu_i}} \tag{18}$$

where ν_i, are the degrees of freedom of each individual uncertainty equal to:

- n-1, for a single quantity estimated from the arithmetic mean of n independent observations (measurement and type A uncertainties);
- $\frac{1}{2}\left[\frac{\Delta u_i}{u_i}\right]^{-2}$ for type B uncertainties having the quantity in large brackets equal to the relative uncertainty of u_i. Refer to GUM:1995, Annex G[1] for more details.

———————

1 *Guide to the expression of uncertainty in measurement* (GUM), published in 1993, corrected and reprinted in 1995. This publication has been replaced by ISO/IEC 98-3:2008 (see Bibliography).

Then, if $\nu_{eff} < 50$, k for a given value of ν can be extrapolated from Table G.2 of GUM:1995[2], which is partially reproduced in Table 7.

Table 7 – Values of k_{95} for different values of ν

ν	k_{95}		ν	k_{95}		ν	k_{95}		ν	k_{95}		ν	k_{95}
1	12,71		6	2,45		11	2,2		16	2,12		25	2,06
2	4,3		7	2,36		12	2,18		17	2,11		30	2,04
3	3,18		8	2,31		13	2,16		18	2,10		35	2,03
4	2,78		9	2,26		14	2,14		19	2,09		40	2,02
5	2,57		10	2,23		15	2,13		20	2,09		45	2,01

8.3.3 Typical values of degree of freedom

Table 8 provides typical values of ν_i, for different contributions.

Table 8 – Typical values of ν_i

Reference	Name	ν_i	Remark
5.2.5.1	Instability of the optical source	200	
5.2.5.2	Relative uncertainty arising from the uncertainty of the optical source wavelength	200	
5.2.5.3	Relative uncertainty due to multimode launch condition	3,7 at 850 nm 4,5 at 1 300 nm	$\frac{\Delta u_i}{u_i}$ =0,368 at 850 nm and 0,333 at 1300 nm
5.2.5.4	Relative uncertainty due to non-linearity of the power meter	200	
5.2.5.5	Relative uncertainty due to finite display resolution of power meter	∞	No uncertainty on this value
5.2.5.6	Relative uncertainty due to power meter spatial uniformity	200	
5.2.5.7	Relative uncertainty due to polarization dependency of power meter	200	
5.2.5.8	Relative uncertainty due to power meter noise	20 000	
5.2.5.9	Relative uncertainty arising from power meter instability	200	
5.2.5.10	Relative uncertainties of the absolute power measurements	200	
5.2.6.1	Mating reproducibility (setup)	5 000	
5.2.6.2	Repeatability of the reference connectors mating	5 000	
5.2.6.3	PDL of the reference APC connectors	200	
5.2.7.1	Mating reproducibility (cabling)	5 000	
5.2.7.2	Relative uncertainty related to the repeatability of the reference connector mating to cabling connectors	5 000	
5.2.7.3	Relative uncertainty related to the PDL of the cabling APC connectors	200	

———————

2 *Guide to the expression of uncertainty in measurement* (GUM), published in 1993, corrected and reprinted in 1995. This publication has been replaced by ISO/IEC 98-3:2008 (see Bibliography).

Annex A
(normative)

Mathematical basis

A.1 General

This annex summarises the form of evaluating, combining and reporting the uncertainty of measurement. It is based on ISO/IEC Guide 98-3:2008 but does not relieve the need to consult this guide for more advice.

This annex 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

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 $\overline{X}$ estimated from n independent repeated observations X_k, the arithmetic mean is:

$$\overline{X} = \frac{1}{n}\sum_{k=1}^{n} X_k \tag{A.1}$$

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:

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

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 $u_{\text{typeA}}(x)$ associated with the estimate x is the experimental standard deviation of the mean:

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

A.3 Type 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:

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

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

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

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.5) 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 evaluations:

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

where

i is the current number of individual contributions;

$u_i(y)$ 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 (7).

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:

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

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 ISO/IEC 98-3:2008). If these conditions are not met, larger coverage factors are to be used to reach these levels of confidence.

Annex B
(informative)

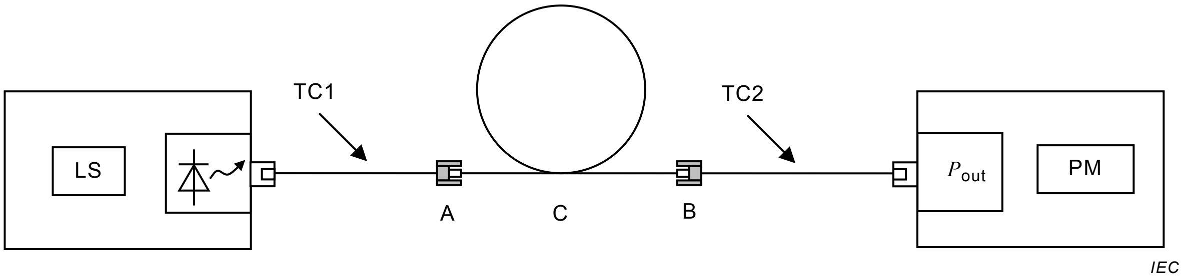
Measurement methods

B.1 Measurement methods as per IEC 61280-4-1 and 61280-4-2

B.1.1 General

Figure B.1, Figure B.2, Figure B.3 and Figure B.4 reproduce measurement configuration diagrams defined in IEC 61280-4-1:2009 and 61280-4-2:2014, Annexes A, B and C. For more details, refer to IEC 61280-4-1 and IEC 61280-4-2.

B.1.2 Measurement configuration



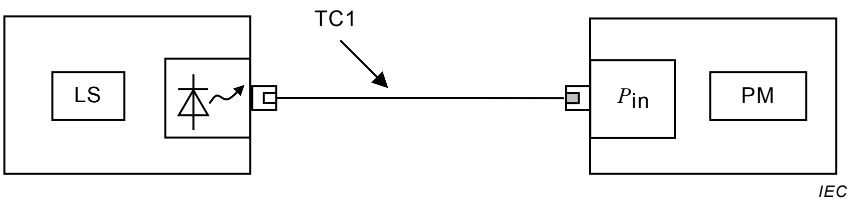
Key

LS light source
TC1 launch cord
C cabling under test
TC2 receive cord
PM power meter

NOTE Reference grade terminations are shaded.

Figure B.1 – Measurement configuration

B.1.3 One-cord reference configuration

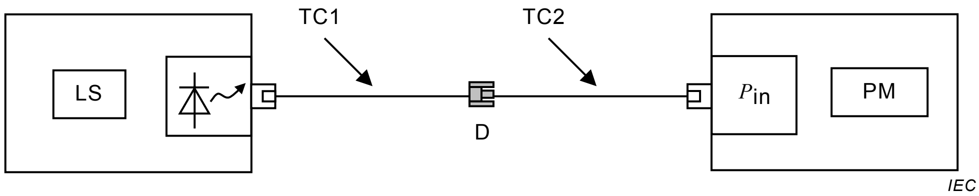


Key

LS light source
TC1 launch cord
PM power meter

Figure B.2 – One-cord reference measurement

B.1.4 Two-cord reference configuration

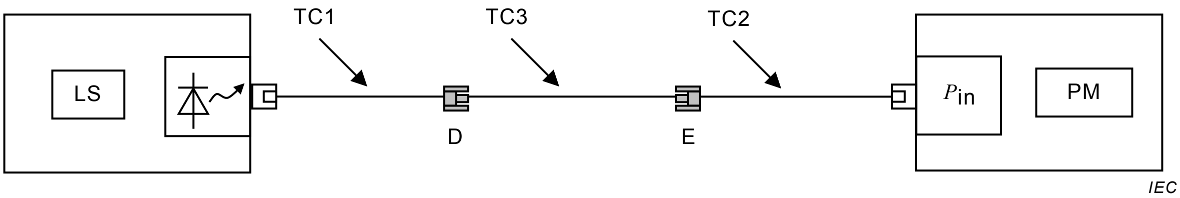


Key

LS	light source	TC2	receive cord
TC1	launch cord	PM	power meter

Figure B.3 – Two-cord reference measurement

B.1.5 Three-cord reference configuration



Key

LS	light source	TC2	receive cord
TC1	launch cord	PM	power meter
TC3	substitution cord		

Figure B.4 – Three-cord reference measurement

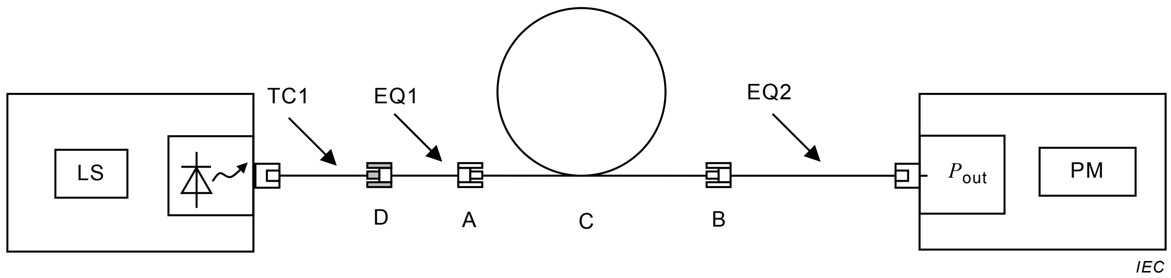
B.2 Measurement methods as per ISO/IEC 14763-3:2014

B.2.1 General

Figure B.5, Figure B.6, Figure B.7 and Figure B.8 reproduce measurement configuration diagrams defined in ISO/IEC 14763-3.

B.2.2 Channels

B.2.2.1 Measurement configuration

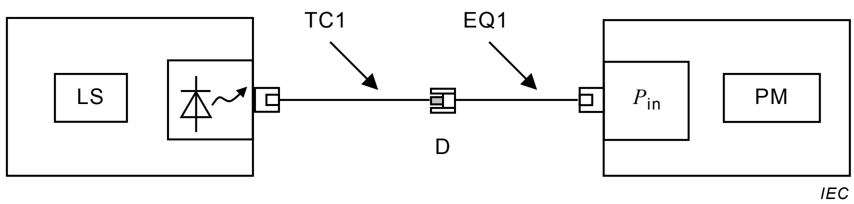


Key

LS	light source	EQ1	equipment launch cord
TC1	launch cord	PM	power meter
C	cabling under test	EQ2	equipment receive cord

Figure B.5 – Measurement on channel

B.2.2.2 Channel reference configuration



Key

LS light source

TC1 launch cord

EQ1 equipment launch cord

PM power meter

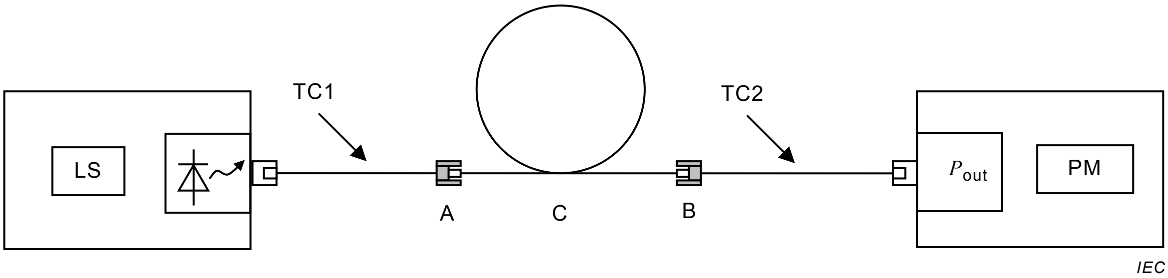
Figure B.6 – Channel reference measurement

B.2.2.3 Uncertainties

For uncertainty aspects, this method is equivalent to the method in IEC 61280-4-1 and IEC 61280 4-2 one-cord method, except for 5.2.7.1 and 5.2.7.2.

B.2.3 Links

B.2.3.1 Measurement configuration



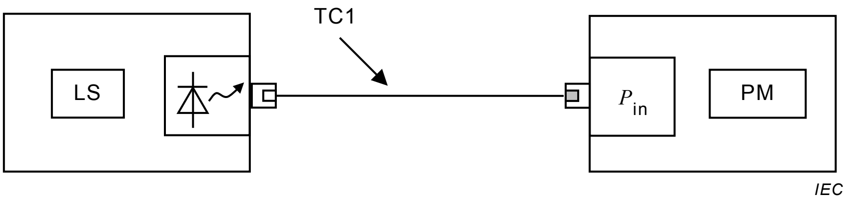
Key

LS	light source	TC2	receive cord	B	Connection point between cabling under test and receive cord
TC1	launch cord	PM	power meter		
C	cabling under test	A	Connection point between launch cord and cabling under test		

NOTE Reference grade terminations are shaded.

Figure B.7 – Link measurement configuration

B.2.3.2 Link reference configuration



Key

LS light source

TC1 launch cord

PM power meter

Figure B.8 – Link reference measurement

B.2.3.3 Uncertainties

For uncertainty aspects, this method is equivalent to the method in IEC 61280-4-1 and IEC 61280-4-2 one-cord method.

Annex C
(normative)

Uncertainties evaluation

C.1 Type A uncertainties

C.1.1 General

Type A uncertainties are evaluated by the statistical analysis of a series of measurements. It is not the objective of this Technical Report to recommend the addition of extra measurements. However, in some cases, a statistical evaluation performed in real conditions can help to reduce a large value of uncertainty extracted from the documentation of the product.

C.1.2 Evaluation of optical source instability and associated uncertainties

Evaluation of the source stability can be performed using the test configuration described in Figure B.2.

After source and power metre warm up, the source power measurement ($P_{t,i}$) is recorded at a regular time interval (Δt) over a long period, making sure the number of individual measurements (m) is greater than 20.

If appropriate, the measurement period should be longer than the period of temperature variation of the measurement environment.

The standard deviation of the relative variation of power measurement can then be calculated from:

$$s_{P,m\Delta t} = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}(P_{t_i} - \frac{1}{m}\sum_{i=1}^{m}P_{t_i})^2} \Bigg/ \left(\frac{1}{m}\sum_{i=1}^{m}P_{t_i}\right) \qquad \text{(C.1)}$$

Then using Equation (A.3), the relative uncertainty due to optical source instability is

$$u_{\text{pstab}} = s_{P,m\Delta t} \qquad \text{(C.2)}$$

C.2 Type B uncertainties

C.2.1 General

Type B uncertainty evaluation is obtained by means other than a statistical analysis of observations. It should be evaluated by scientific judgement based on all available information. The following clauses provide guidance for evaluation.

C.2.2 Evaluation of the power meter noise

In some cases, information on the optical power meter noise is provided by the supplier. When this information is available, the relative uncertainty arising from the power meter noise is equal to the noise power (peak to peak) divided by the minimum measured power level.

For example, if a power meter having a noise level of 100 pW peak to peak is used to measure a 30 dB attenuation cabling in conjunction with a 0 dBm source (1 mW), the relative uncertainty arising from the power meter noise is:

$$u_{P_{\text{noise}}} = \frac{P_{\text{noise}}}{P_{\text{out min}}} = \frac{100\ \text{pW}}{1\,\text{mW}/1000} = 10^{(-10+3+3)} = 0{,}0001 \rightarrow 0{,}01\% \tag{C.3}$$

The noise generated by the photodiode and the electronics of the power meter limits the measurement range. If the optical power meter noise value is not available, it can be estimated as 20 % of the minimum value of the measurement range.

C.2.3 Elements to be considered for power meter stability analysis

Short and long term instability of the power meter cannot be easily separated from the instability of the source. When determining Type A uncertainty of the optical source as described in C.1.2, the instability of the power is also recorded.

If, during measurement, the power meter operates in environmental conditions used to determine source instability, then additional contribution should be considered equal to zero.

If the power meter operates in different environmental conditions (temperature and relative humidity), the additional contribution of uncertainty shall be determined from the documentation of the power meter.

In many cases, the documentation of the power meter may not be able to provide temperature and humidity dependence of the product. Therefore, it is recommended to characterise the stability of the source over the full range of environmental conditions applicable to both source and power meter over the duration of measurement.

C.2.4 Evaluation of the centre wavelength dependence

C.2.4.1 Principle

Assuming the cabling attenuation wavelength dependence is equivalent to the fibre attenuation wavelength dependence, Equation (A.8) can be used to determine the sensitivity factor of the uncertainty arising from the uncertainty of the source wavelength.

Locally, the spectral attenuation of a fibre can be estimated using a polynomial equation such as:

$$\alpha_{(\lambda)} = \alpha_0 + \alpha_1\lambda + \alpha_2\lambda^2 + \alpha_3\lambda^3 + \alpha_4\lambda^4 + \alpha_5\lambda^5 + \alpha_6\lambda^6 \tag{C.4}$$

The derivative of this function is the sensitivity coefficient $c_{(\lambda)}$:

$$c_{(\lambda)} = \frac{\partial\alpha_{(\lambda)}}{\partial\lambda} = \alpha_1 + 2\alpha_2\lambda + 3\alpha_3\lambda^2 + 4\alpha_4\lambda^3 + 5\alpha_5\lambda^4 + 6\alpha_6\lambda^5 \tag{C.5}$$

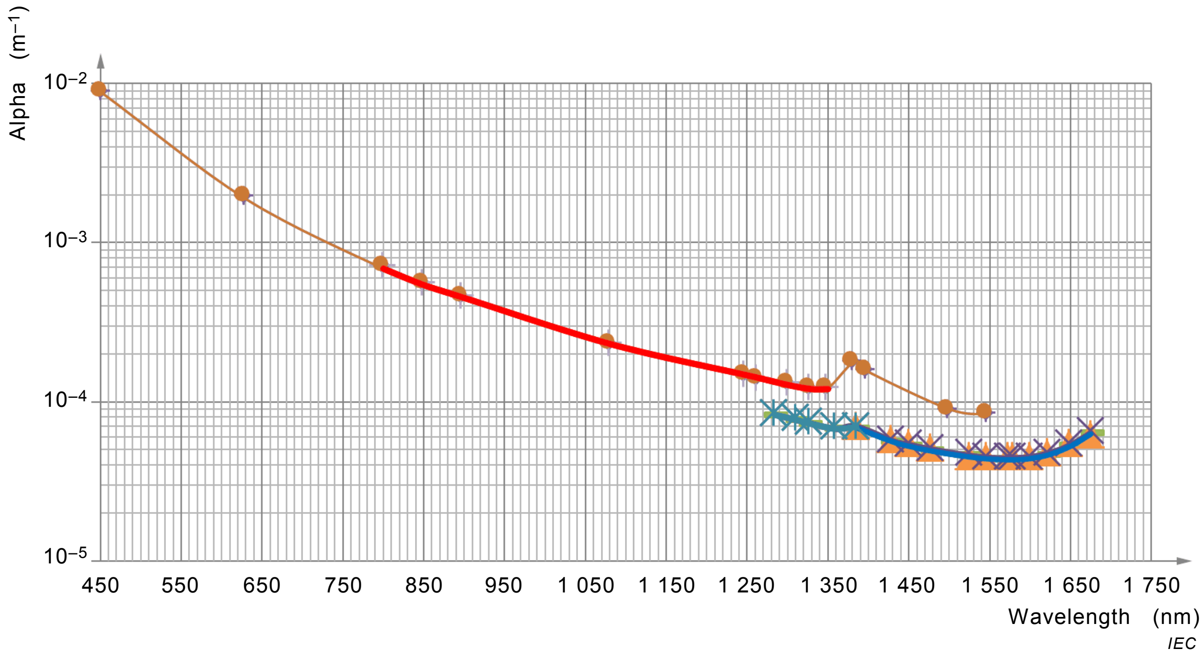
where λ is the selected measurement wavelength (e.g. typically 850 nm, 1 300 nm, 1 310 nm or 1 550 nm).

Therefore, standard Equation (A.8) becomes:

$$u_{(\lambda s)} = c_{(\lambda)} \times u_{(\lambda)} \tag{C.6}$$

C.2.4.2 Application

The typical fibre spectral attenuation given Figure C.1 can be used to determine Equation (C.4) coefficients.



Key

Red MM A1 type fibre

Blue SM B1.3 type fibre

Figure C.1 – Typical spectral response of a fibre

Table C.1 provides coefficient values determined from the curve shown in Figure C.1.

Table C.1 – Spectral attenuation coefficients

	Domain nm	α_0	α_1	α_2	α_3	α_4	α_5	α_6
MM A1	800 to 1 350	$5{,}241\ 88 \times 10^{-01}$	$2{,}937\ 83 \times 10^{-03}$	$6{,}850\ 36 \times 10^{-06}$	$8{,}485\ 88 \times 10^{-09}$	$5{,}883\ 55 \times 10^{-12}$	$-2{,}163\ 8 \times 10^{-15}$	$3{,}297\ 25 \times 10^{-19}$
SM B1.3	1 285 to 1 385	$-7{,}510\ 8 \times 10^{-02}$	$1{,}719\ 89 \times 10^{-04}$	$1{,}309\ 54 \times 10^{-07}$	$3{,}318\ 81 \times 10^{-11}$	0	0	0
SM B1.3	1 385 to 1 675	$1{,}375\ 6 \times 10^{-01}$	$3{,}623\ 94 \times 10^{-04}$	$3{,}586\ 79 \times 10^{-07}$	$1{,}579\ 87 \times 10^{-10}$	$2{,}612\ 47 \times 10^{-14}$		

Sensitivity coefficients determined from Table C.1 using Equation (C.6) are given in Table C.2.

Table C.2 – Sensitivity coefficients

λ	Fibre	$c(\lambda)(m^{-1})$
850 nm	MM A1 fibre	$-2{,}204\times10^{-06}$
1 300 nm	MM A1 f	$-3{,}390\times10^{-07}$
1 310 nm	SM B1.3 f	$-2{,}482\times10^{-07}$
1 550 nm	SM B1.3 f	$-3{,}993\times10^{-08}$

λ	**Fibre**	**c(λ)(m^{-1})**
1 625 nm	SM B1.3 f	$+1{,}655\times10^{-07}$

Example:

When the centre wavelength of a 1 310 nm single mode source is known with an uncertainty of 30 nm, the uncertainty contribution for one meter of fibre is:

$$\mu_{\lambda s} = c(\lambda)\cdot U(\lambda) = -2{,}482\cdot 10^{-7}\times 30 = -7{,}446\cdot 10^{-6}\ \text{m}^{-1} \quad \text{(C.7)}$$

This represents 0,032 dB/km.

C.2.5 Spectral width dependence

When the source spectrum is symmetrical, and when the spectral attenuation curve does not exhibit an inflexion point, the variation of spectral width does not impact the measurement.

C.2.6 Evaluation of the uncertainties due to MM launch conditions

The encircled flux limits are intended to constrain loss variation, relative to the loss measured by a source exactly on the target launch, to be no greater than the larger of ±0,1 times the attenuation value in dB or the threshold value (see IEC 62614:2010, 5.6).

For example, a threshold value of 0,08 dB means that the loss variation is usually expected to be within ±0,1 times the loss value for losses equal to or greater than 0,8 dB, and within 0,08 dB for losses less than 0,8 dB.

Recent analysis (to be published in 2016) is showing that at 1 300 nm and 50 μm, loss variation may only be constrained within ±0,2 times the attenuation value in dB. As uncertainties calculation should always be conservative, it is recommended to use this new value for 1 300 nm and 50 μm.

Figure C.2 provides uncertainty values to be used for a given measured loss (having different wavelengths and fibres).

NOTE In the attenuation model, the uncertainties come from a limited number of connectors. The number of connectors is too small to allow the validity of the central limit theorem. Therefore the distribution of the uncertainty is considered as rectangular.

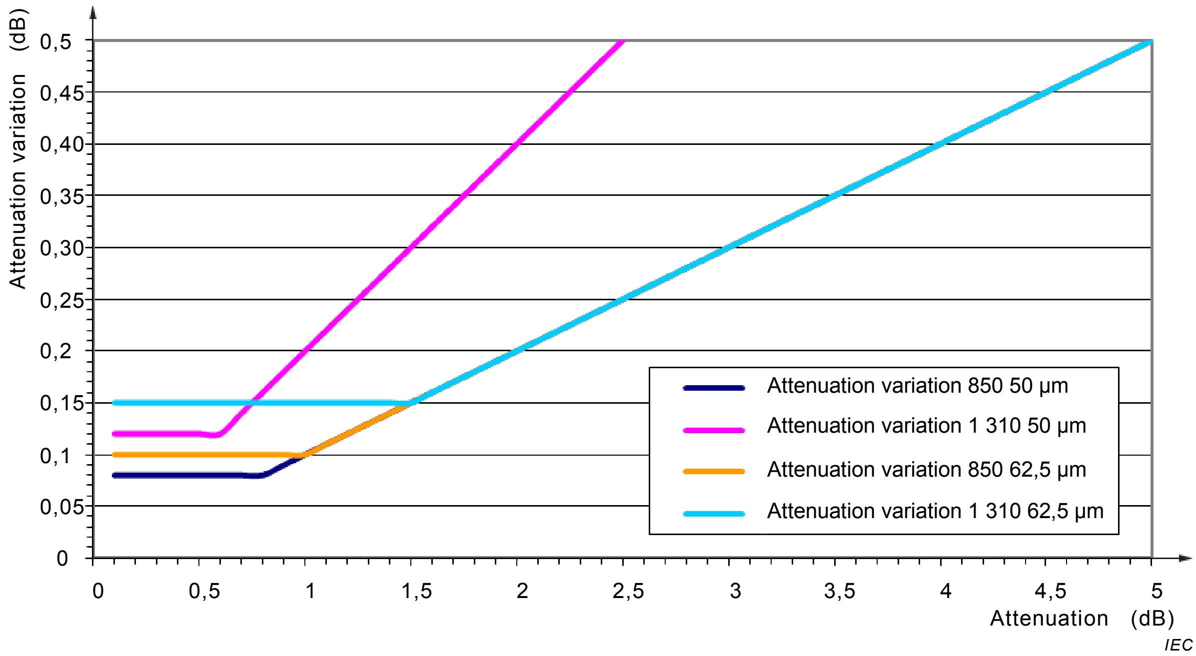


Figure C.2 – Uncertainties due to the launch conditions for a given loss

C.2.7 Evaluation of the PDL

PDL of an APC connector can be estimated assuming the transmitted power depending upon the polarization state of the light that may vary in any direction (e.g. from parallel to perpendicular).

$$PDL = 10\log_{10}\left(\frac{Ts^2}{Tp^2}\right) \tag{C.8}$$

$$Ts = 1 - \left[\frac{n_1\cos\theta_i - n_2\sqrt{1-\left(\frac{n_1}{n_2}\sin\theta_i\right)}}{n_1\cos\theta_i + n_2\sqrt{1-\left(\frac{n_1}{n_2}\sin\theta_i\right)}}\right]^2 \tag{C.9}$$

$$Tp = 1 - \left[\frac{n_1\sqrt{1-\left(\frac{n_1}{n_2}\sin\theta_i\right)} - n_2\cos\theta_i}{n_1\sqrt{1-\left(\frac{n_1}{n_2}\sin\theta_i\right)} + n_2\cos\theta_i}\right]^2 \tag{C.10}$$

where

Ts and Tp are the transmitted coefficient for parallel and perpendicular polarization;

n_1 and n_2 are respectively the refractive index of the fibre and of the air;

θ_i is the angle of the connector.

For example, at 1 550 nm, assuming the air index is 1,000 26 and the fibre index is 1,468 16, the PDL is 0,018 dB for an 8° angled connector.

C.2.8 Uncertainty of absolute power measurement

C.2.8.1 General

When two different power meters are used, the uncertainty due to the optical power metre absolute calibration u_{abs} needs to be determined from the absolute uncertainty at operating conditions of each optical power meters $u_{\text{abs\_operating},i}$.

IEC 61315:2005, 6.2 can be used to determine $u_{\text{abs\_operating},i}$. taking into consideration the absolute calibration at reference conditions and all operation conditions such as maximum span between calibration, ambiance temperature, power measuring range, wavelength range, etc.

C.2.8.2 Calculation

When $u_{\text{abs\_operating},i}$ is determined for each optical power meter, the uncertainty of absolute power measurement can be calculated from Equation C.11.

$$u_{\text{abs}} = \sqrt{\left(u_{\text{abs\_operating,1}}\right)^2 + \left(u_{\text{abs\_operating,2}}\right)^2} \quad \text{(C.11)}$$

Annex D
(normative)

Typical values of uncertainties

Table D.1 provides typical values of uncertainty contributions that can be used for calculation. The table also provides the correspondence with IEC TR 62627-04.

Table D.1 – Typical values of uncertainties

Reference	Source of uncertainty / Default value	Typical value	Comments	Reference IEC TR 62627-04 [a] (*i* in Table 1)
5.2.5.1	Relative uncertainty arising from the instability of the optical source[a)]	0,05 dB		(6)
5.2.5.2	Relative attenuation uncertainty arising from the uncertainty of the optical source wavelength	$f(\lambda)$	See C.2.4	
5.2.5.3	Relative uncertainty due to the multimode launch condition	$f(Att)$	See C.2.6	
5.2.5.4	Relative uncertainty arising from the non-linearity of the power meter	0,005 dB		(4)
5.2.5.5	Relative uncertainty arising from the finite display resolution of power meter	0,005 dB		(3)
5.2.5.6	Relative uncertainty arising from power meter spatial uniformity [b)]	0		(5)
5.2.5.7	Relative uncertainty arising from the polarization dependency of power meter	0,005 dB or 0,01 dB	PC connectors: 0,005 dB otherwise: 0,01 dB	(2)
5.2.5.8	Relative uncertainty arising from power meter noise	$f(noise\ level)$	See C.2.2 noise level = 100 pW	
5.2.5.9	Relative uncertainty arising from power meter instability	0,004 dB		
5.2.5.10	Relative uncertainties of the absolute power measurements	0,2 dB		
5.2.6.1	Relative uncertainties due to mating reproducibility	0,1 dB		(9)
5.2.6.2	Relative uncertainty related to the repeatability of the reference connector mating	0,05 dB		(8)
5.2.6.3	Relative uncertainty related to the PDL of the reference APC connectors	0,018 dB	Only if APC	(7)
5.2.7.1	Relative uncertainties due to mating reproducibility	0,1 dB		(9)
5.2.7.2	Relative uncertainty related to the repeatability of the reference connector mating to cabling connectors	0,05 dB		(8)
5.2.7.3	Relative uncertainty related to the PDL of the cabling APC connectors	0,018 dB	Only if APC	(7)

NOTE This table is not valid for multimode fibres type A2, A3 and A4.

a) The typical value for 5.2.5.1 is higher than the equivalent typical value in IEC TR 62627-04, because the time between P_{in} and P_{out} measurements can be longer.

b) Only when using both PC and APC connectors. The coefficient shall be equal to zero if the same type of connector is used. See Tables 5 and 6.

Annex E
(informative)

Linear to dB scale conversion of uncertainties

E.1 Definition of decibel

The decibel is a submultiple of 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:

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

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

E.2 Conversion of relative uncertainties

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

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

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

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

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

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

that leads to:

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

and two useful expressions:

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

Bibliography

IEC 61315:2005, *Calibration of fibre-optic power meters*

IEC 62614:2010, *Fibre optics – Launch condition requirements for measuring multimode attenuation*

IEC TR 62627-04, *Fibre optic interconnecting devices and passive components – Part 04: Example of uncertainty calculation: Measurement of the attenuation of an optical connector*

ISO/IEC Guide 99:2007, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

ISO/IEC 14763-3:2014, *Information technology – Implementation and operation of customer premises cabling – Part 3: Testing of optical fibre cabling*

Bell, Stephanie: *A Beginner's Guide to Uncertainty of Measurement*. Measurement Good Practice Guide. No. 11 – NPL.

Birch, Keith: *Estimating Uncertainty in Testing*. Measurement Good Practice Guide. No. 36 – NPL.

This page deliberately left blank

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Copyright in BSI publications

Storing and using standards

Standards purchased in soft copy format:

- A British Standard purchased in soft copy format is licensed to a sole named user for personal or internal company use only.
- The standard may be stored on more than 1 device provided that it is accessible by the sole named user only and that only 1 copy is accessed at any one time.
- A single paper copy may be printed for personal or internal company use only.

Standards purchased in hard copy format:

- A British Standard purchased in hard copy format is for personal or internal company use only.
- It may not be further reproduced – in any format – to create an additional copy. This includes scanning of the document.

If you need more than 1 copy of the document, or if you wish to share the document on an internal network, you can save money by choosing a subscription product (see 'Subscriptions').

Reproducing extracts

For permission to reproduce content from BSI publications contact the BSI Copyright & Licensing team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email subscriptions@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Useful Contacts

Customer Services
Tel: +44 345 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 345 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.