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TECHNICAL REPORT

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

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IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDELINES –

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FOREWORD

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IEC TR 61282-14 has been prepared by 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics. It is a Technical Report.

This document contains an attached file in the form of an Excel spreadsheet. This file is intended to be used as a complement and does not form an integral part of the document.

This third edition cancels and replaces the second edition published in 2019. This edition constitutes a technical revision.

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

a) addition of uncertainties calculation for optical time domain reflectometer (OTDR) measurement methods based on the analysis provided in 61280-4-3;

b) addition of uncertainties calculation for passive optical networks (PON);

c) update of the list of reference grade connectors;

d) addition of probability distribution in Table D.1.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
86C/1913/DTR	86C/1923/RVDTR

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61282 series, published under the general title *Fibre optic communication system design guidelines,* 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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

Reference documents such as ISO/IEC Guide 98-3, *Guide to the uncertainty of measurement (GUM)*, detail methods for the determination of the uncertainty of a measurement.

This document shows a practical application of these methods for the determination of the uncertainty in attenuation measurements of fibre optic cabling as defined in IEC 61280-4-1, IEC 61280-4-2, and IEC 61280-4-3, using optical light sources and power meters or OTDRs, with the exception of multimode OTDRs.

It includes the review of all contributing factors to uncertainty (such as launch conditions, spectral width, stability of source, power meter polarization, resolution, linearity, and quality of test cord connectors) to determine the overall measurement uncertainty. This part of IEC 61282 applies to the measurement of single-mode or multimode fibres without restrictions to the fibre parameters, including mode field diameter, core diameter, and NA. 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 document is related to this particular application and measurement conditions that are compliant with measurement requirements defined by IEC 61280-4-1, IEC 61280-4-2, and IEC 61280-4-3.

The reference document for general uncertainty calculations is ISO/IEC Guide 98-3, and this document does not intend to replace it. This document only presents examples, and it is good practice to use it in conjunction with ISO/IEC Guide 98-3. A brief introduction to the determination of measurement uncertainty according to ISO/IEC Guide 98-3 is given in Annex A.

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

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDELINES –

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 a detailed analysis and calculations 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. It also includes simplified analysis and calculation of the uncertainties related to the measurement of the attenuation of single-mode optical fibre cabling using OTDRs.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

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

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

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

3.1.1
attenuation
A
reduction of optical power induced by transmission through a medium such as cabling, characterized by

$$A_{\mathrm{dB}} = 10 \times log_{10}\left(P_{\mathrm{in}}/P_{\mathrm{out}}\right)$$

where

P_{in} and P_{out} are the optical powers into and out of the cabling, typically measured in mW

Note 1 to entry: Attenuation is expressed in dB.

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 attenuation to a variation of the state of polarization (SOP) over all SOPs

Note 1 to entry: PDL is expressed in dB.

3.1.7
nonlinearity
NL
relative difference, for a power meter, between the response at a given input power P and the response at a reference input power P_0, characterized by

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

where

$r(P) = P_{read}(P)/P$ is the response of the power meter at input power P;

$P_{read}(P)$ is the reading of the power meter at input power P

Note 1 to entry: If expressed in decibels, the nonlinearity is calculated as:

$$R_{NLdB}(P/P_0) = 10 \times \log_{10}\left[\frac{r(P)}{r(P_0)}\right]$$

Note 2 to entry: The nonlinearity is equal to zero at the reference power.

3.1.8
uncertainty of measurement
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

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
type A uncertainty
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: For further information, see A.2 and ISO/IEC Guide 98-3.

3.1.14
type B uncertainty
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: For further information, see A.3 and ISO/IEC Guide 98-3.

3.2 Abbreviated terms

APC angled physical contact (description of connector style)

LSPM light source power meter

NA numerical aperture

OPM optical power meter

OTDR Optical time domain reflectometer

PC physical contact (description of connector style that is not angled)

PON passive optical network

4 Overview of uncertainty

4.1 What is uncertainty?

According to ISO/IEC Guide 98-3 (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 could observe variations of the displayed power level on the power meter and, hence, be unable to decide which value to record. 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 could 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 the attenuation of cabling that is composed of different fibres, the mode field diameters or numerical apertures (NA) of the different fibres in the cabling are usually unknown; however, a mismatch of these parameters can significantly contribute to the measured attenuation.

Also, poor knowledge of measurement conditions generates uncertainties, but itself 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 <1 nm, the measurement condition can be precisely specified. 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 can 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 Test methods

Four attenuation test 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 methods are designated respectively,

- one-cord,
- three-cord,
- two-cord, and
- equipment cord 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 B.1).

Additionally, one test method uses an OTDR to determine the attenuation of the cabling under test (see Annex B).

When the cabling under test is a PON, the one-cord method using a light source and a power meter and two OTDR methods can be used (see Annex B).

Refer to IEC 61280-4-1, IEC 61280-4-2, and IEC 61280-4-3 for more details.

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

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 uncertainties listed 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 nonlinearity	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
OTDR wavelength	Measurement devices	13
OTDR spectrum (spectral width)	Measurement devices	14
OTDR nonlinearity	Measurement devices	15
OTDR reading resolution	Measurement devices	16
OTDR cursors placement	Measurement devices	17
OTDR noise	Measurement devices	18
Test cord connector or fibre attenuation uncertainty	References used	19
Connector mating repeatability (test cord or cabling)	References used or item to be measured	20
Connector PDL	References used or item to be measured	21
Reflections (FP cavity)	References used or item to be measured	22
Connector end face cleanliness	Operator skills	23
Fibre handling	Operator skills	24
Calculation errors	Measurement process	25
NA of the fibre	Item to be measured	26
Core diameter of the fibre or mode filed diameter	Item to be measured	27
Fibre nonlinearity	Item to be measured	28
Fibre backscatter coefficient	Item to be measured	29
Spectral dependence of splitters	Item to be measured	30
Temperature	Environment	31
Humidity	Environment	32

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