IEC/TR 62627-04

Edition 1.0 2012-07

TECHNICAL REPORT

Fibre optic interconnecting devices and passive components – Part 04: Example of uncertainty calculation: Measurement of the attenuation of an optical connector

IEC/TR 62627-04:2012(E)

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

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

Useful links:

IEC publications search - www.iec.ch/searchpub

The advanced search enables you to find IEC publications by a variety of criteria (reference number, text, technical committee,…).
It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available on-line and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary (IEV) on-line.

Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

IEC/TR 62627-04

Edition 1.0 2012-07

TECHNICAL REPORT

Fibre optic interconnecting devices and passive components – Part 04: Example of uncertainty calculation: Measurement of the attenuation of an optical connector

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE **S**

ICS 33.180.20

ISBN 978-2-83220-212-8

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

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS –

Part 04: Example of uncertainty calculation: Measurement of the attenuation of an optical connector

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.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

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 62627-04, which is a technical report, has been prepared by subcommittee 86B: Fibre optic interconnecting devices and passive components, of IEC technical committee 86: Fibre optics.

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

Enquiry draft	Report on voting
86B/3374/DTR	86B/3427/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.

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

A list of all the parts in the IEC 62627 series, published under the general title *Fibre optic interconnecting devices and passive components* 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 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.

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

INTRODUCTION

The IEC 61300-3 series is a library of measurement methods for fibre optic passive components.

These standards describe the necessary equipment and procedures to measure a specific quantity. The uncertainty budget of every measurement is a key parameter, which should be determined by applying dedicated statistical methods as extensively presented in reference documents like ISO/IEC Guide 98-3:2008.

This technical report shows a possible simple application of these methods for the determination of the measurement uncertainty of optical low loss connector attenuation measurements as defined in IEC 61300-3-4. A detailed analysis of the main uncertainty contributions for single and for repeated measurements is shown, and a full mathematical development of the uncertainty budget is given in Annex B. The difference in uncertainty estimation for the measurement of an optical connection compared to the measurement of an optical connector against a reference connector is also discussed.

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 combination with ISO/IEC Guide 98-3:2008. A brief introduction to the determination of a measurement uncertainty according to ISO/IEC Guide 98-3:2008is given in Annex A.

Uncertainty calculations should preferably be performed using a linear representation of the relevant quantities. In this document all calculations are performed using linear scales but results are also presented in logarithmic scale, since logarithmic units such as dB or dBm are in common use in fibre optics. This analysis assumes uncorrelated quantities, which is usually an acceptable assumption when considering simple attenuation measurements.

All numbers presented in this document are related to this particular example and should not be taken as standard values.

FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS –

Part 04: Example of uncertainty calculation: Measurement of the attenuation of an optical connector

1 Scope

This Technical Report represents a selected example that concerns the measurement of the attenuation of passive optical components (IEC 61300-3-4), particularly focussed on insertion method B for low-loss optical connectors assembled on SM optical fibre (according to IEC 60793-2-50, Type B1.3).

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

IEC 61300-3-4, *Fibre Optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-4: Examinations and measurements – Attenuation*

IEC 61755-1, *Fibre optic connector optical interfaces – Part 1: Optical interfaces for single mode non-dispersion shifted fibres – General and guidance*

IEC 61755-3-9, *Fibre optic interconnecting devices and passive components – Fibre optic connector optical interfaces – Part 3-9: Optical interface, 2,5 mm and 1,25 mm diameter cylindrical PC ferrule for reference connector, single mode fibre*

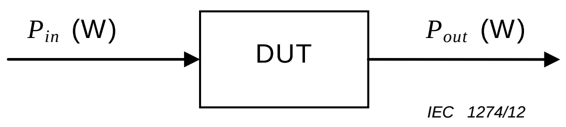
IEC 61755-3-10, *Fibre optic interconnecting devices and passive components – Fibre optic connector optical interfaces – Part 3-10: Optical interface, 2,5 mm and 1,25 mm diameter cylindrical APC ferrule for reference connector, single mode fibre*

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

3 Measurement of attenuation

3.1 General

Attenuation measurement is intended to give a value for the decrease of useful power, expressed in decibels, resulting from the insertion of a device under test (DUT), within a length of optical fibre cable as shown in Figure 1.



$$A[\text{dB}] = -10 \cdot \log\left(\frac{P_{out}}{P_{in}}\right)$$

where

P_{in} and P_{out} are expressed in W

attenuation, A, is expressed in dB

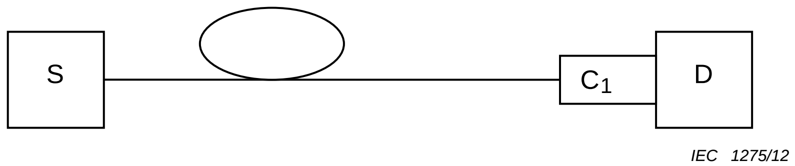
Figure 1 – Schematic representation of an attenuation measurement

3.2 Attenuation measurement for optical connectors

The most common method used for the attenuation measurement of optical connectors is defined in IEC 61300-3-4 as “insertion method B”. This technical report concentrates on the uncertainty estimation for this particular method.

Insertion method B is based on the use of an input connector (measurement plug) for the measurement of P_{in} (reference power).

Light source (S) and power meter (D) properties shall be as defined in IEC 61300-3-4. For the scope of this document, the source shall be of type S4 or S5 (single mode source at 1 310 nm or 1 550 nm)



Key

S light source

D detector

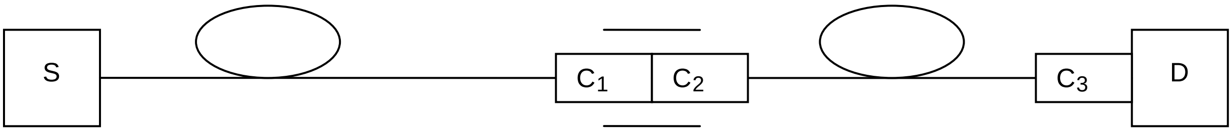
C_1 measurement plug

Figure 2 – Measurement of P_{in}

A DUT connector (C_2), assembled on a patchcord, is then connected to C_1, with the second connector C_3 placed in front of the detector (see Figure 2 and Figure 3). Any change in the measured power can be attributed to the additional connection between C_1 and C_2 under the assumptions that:

The attenuation caused by the additional fibre length of the patchcord is negligible.

The situation at the plug – detector interface is the same for P_{in} as for P_{out} measurements.



Key

S light source

D detector

C_1 measurement plug

C_2 plug connected to C1

C_3 second connector

Figure 3 – Measurement of P_{out}

Based on the above assumptions, the connection (C_1 – C_2) attenuation (also called Insertion Loss) can be calculated as follows:

A[dB] = $- 10 \log (P_{out\,\mathrm{W}} / P_{in\,\mathrm{W}})$ for power measurement values expressed in W (1a)

A[dB] = $P_{in} - P_{out}$ for power measurement values expressed in dBm (1b)

3.3 Insertion loss measurement using a reference connector

Although the attenuation measurement is the measurement of the additional loss caused by the insertion of an optical connection in the line, and therefore comprises of 2 optical connector plugs and one adapter, it is common use in the industry to use this type of measurement to verify the quality of one single optical connector by performing attenuation measurement using reference connectors and adapters.

Reference connectors and adaptors are components with tightened tolerances and give more reproducible results when the same connector is measured in different laboratories using different reference connectors and adapters. These types of components are currently in the process of standardization (IEC 61755-3-9 and IEC 61755-3-10).

4 Uncertainty estimation

4.1 General

The relative uncertainty of the attenuation A is derived from the uncertainty of the reference power P_{in} and of P_{out} measurements and by considering supplementary contributions, which will be discussed in the next clauses.

In addition, we shall consider following two situations:

a) The attenuation measurement of a connection (C_1 – C_2).

b) The attenuation measurement of one connector (C_2) using a reference connector plug (C_1). In this case, the attenuation value is attributed to C_2 and measurement may vary when changing reference connector and or adaptor, thus representing one additional source of uncertainty.

4.2 Uncertainty calculation

For the calculation of the uncertainty of attenuation measurement according to IEC 61300-3-4, method B, the following equation is valid (for details of the calculation, see Annex B and more particularly Formula (B.1b)):

$$u_A \approx \sqrt{2 \cdot u_{TypeA}{}^2 + 2 \cdot u_{PDR}{}^2 + 2 \cdot u_{Displ}{}^2 + u_{Lin}{}^2 + u_{Unif}{}^2 + 2 \cdot u_{P_{stab}}{}^2 + 2 \cdot u_{PDL}{}^2 + u_{mating}{}^2 + u_{ref}{}^2} \qquad (2)$$

where

u_{TypeA} is the type A relative uncertainty in case of repeated measurements of optical power, or is given by the relative repeatability ΔP_{rep} of the power meter in case of a single measurement, namely $u_{TypeA} = \Delta P_{rep} / \sqrt{3}$;

u_{Pstab} is the relative uncertainty arising from the stability of the optical source;

u_{PDR} is the relative uncertainty arising from the polarization dependency of the responsivity of the power meter;

u_{PDL} is the relative uncertainty arising from the polarization dependant losses of the fibre and of the connector;

u_{Displ} is the relative uncertainty arising from the finite display resolution of the power meter;

u_{Lin} is the relative uncertainty arising from the non-linearity of the power meter;

u_{Unif} is the relative uncertainty arising from the uniformity of the power meter and from possible reflection effects between the detector and the ferrule;

u_{ref} is the uncertainty due to the use of different reference connectors. This contribution is only relevant when measuring the attenuation of a single connector by comparison with a reference connector;

u_{Mating} is the relative uncertainty related to the repeatability of the connector mating.

In order to separate uncertainties due to the power meter, due to the light source and due to the device under test (DUT), the following definitions are useful:

$$u_{instr}{}^2 = 2 \cdot u_{PDR}{}^2 + 2 \cdot u_{Displ}{}^2 + u_{Lin}{}^2 + u_{Unif}{}^2 + 2 \cdot u_{TypeA}{}^2 \qquad (3)$$

$$u_{source}{}^2 = 2 \cdot u_{Pstab}{}^2 \qquad (4)$$

$$u_{DUT}{}^2 = u_{mating}{}^2 + 2 \cdot u_{PDL}{}^2 + u_{\mathrm{Re}\,f}{}^2 \qquad (5)$$

Formula (2) can then be simplified to the following form using Formulas (3) to (5):

$$u_A = \sqrt{u_{instr.}{}^2 + u_{source}{}^2 + u_{DUT}{}^2} \qquad (6)$$

4.3 Evaluation of uncertainty

In Table 1 to Table 4 the uncertainties evaluated in the case of a single measurement of attenuation performed on grade B (according to IEC 61755-1) optical connectors assembled on single mode fibre (B1.3 according to IEC 60793-2-50) are presented. The presented values are given based on the experience acquired in one laboratory and may vary as a function of the instrument used. The error sources are given in dB, since these units are more familiar to the fibre optics industry, but are then transformed into a percentage for the uncertainty calculations.

Uncertainties have been grouped in instrument uncertainties, light source uncertainties and device under test uncertainties. For each group of uncertainty the combined uncertainty has been calculated.

Table 1 – Evaluation of the uncertainty contribution due to the power meter for the measurement of the attenuation of an optical connection

	Error source[1,2]	Uncertainty[2]		Probability distribution[3]	Divisor[3]	Standard uncertainty[4]	Sensitivity coefficient[5]	Uncertainty contribution
i	X_i	u (dB)	u (%)			$u(x_i)$ (%)	c_i	$u_i(y)$ (%)
1	u_{TypeA}	0,005	0,12 %	rect	1,732 1	0,07 %	√2	0,10 %
2	u_{PDR}	0,005	0,12 %	rect	1,732 1	0,07 %	√2	0,10 %
3	u_{Displ}	0,005	0,12 %	rect	1,732 1	0,07 %	√2	0,10 %
4	u_{Lin}	0,005	0,12 %	normal	1	0,12 %	1	0,12 %
5	u_{Unif}	0,02	0,46 %	rect	1,732 1	0,27 %	1	0,27 %
							$u_{instr} = \sqrt{\sum_{i=1}^{5} u_i^{\,2}} =$	0,34 %

1) The uncertainty values listed in this table may vary as a function of the measurements laboratory, of the type of instrument used and as a function of measured DUT (for this example the DUT is a connection of Grade B connectors assembled on standard B1.3 single mode fibre, APC polished).

2) Definition of the error sources is the same as in 4.2. The errors have been estimated in dB's and were then transformed into a percentage for all further calculations.

3) Probability distributions are estimated for single measurements to be rectangular. For rectangular probability distributions the uncertainty has to be divided by $\sqrt{3}$ = 1,7321.

4) Standard uncertainty is obtained by dividing the uncertainty by the divisor.

5) Sensitivity coefficient is obtained directly from Formula 2.

6) The values have been rounded up to get conservative results.

Table 2 – Evaluation of uncertainty contribution due to the light source for the measurement of the attenuation of an optical connection

	Error source[1,2]	Uncertainty[2)]		Probability distribution[3)]	Divisor[3)]	Standard uncertainty[4)]	Sensitivity coefficient[5)]	Uncertainty contribution
i	X_i	u (dB)	u (%)			$u(x_i)$ (%)	c_i	$u_i(y)$ (%)
6	u_{Pstab}	0,01	0,23 %	rect	1,732 1	0,13 %	√2	0,19 %
						$u_{stab} = \sqrt{\sum_{i=6}^{6} u_i^2} =$		0,19 %

1) The uncertainty values listed in this table may vary as a function of the measurements laboratory, of the type of instrument used and as a function of measured DUT (for this example the DUT is a connection of Grade B connectors assembled on standard B1.3 single mode fibre, APC polished).

2) Definition of the error sources is the same as in 4.2. The errors have been estimated in dB's and were then transformed into a percentage for all further calculations.

3) Probability distributions are estimated for single measurements to be rectangular. For rectangular probability distributions the uncertainty has to be divided by $\sqrt{3}$ = 1,7321.

4) Standard uncertainty is obtained by dividing the uncertainty by the divisor.

5) Sensitivity coefficient is obtained directly from Formula 2.

6) The values have been rounded up to get conservative results.

Table 3 – Evaluation of uncertainty contribution due to the device under test for the measurement of the attenuation of an optical connector against reference connector (u_{ref} included)

	Error source[1,2]	Uncertainty[2)]		Probability distribution[3)]	Divisor[3)]	Standard uncertainty[4)]	Sensitivity coefficient[5)]	Uncertainty contribution
i	X_i	u (dB)	u (%)			$u(x_i)$ (%)	c_i	$u_i(y)$ (%)
7	u_{PDL}	0,01	0,23 %	rect	1,732 1	0,13 %	1.414	0,18 %
8	u_{mating}	0,05	1,16 %	rect	1,732 1	0,67 %	1	0,67 %
9	u_{ref}	0,1	2,33 %	rect	1,732 1	1,34 %	1	1,35 %
						$u_{DUT} = \sqrt{\sum_{i=7}^{9} u_i^2} =$		1,509 %

1) The uncertainty values listed in this table may vary as a function of the measurements laboratory, of the type of instrument used and as a function of measured DUT (for this example the DUT is a connection of Grade B connectors assembled on standard B1.3 single mode fibre, APC polished).

2) Definition of the error sources is the same as in 4.2. The errors have been estimated in dB's and were then transformed into a percentage for all further calculations.

3) Probability distributions are estimated for single measurements to be rectangular. For rectangular probability distributions the uncertainty has to be divided by $\sqrt{3}$ = 1,7321.

4) Standard uncertainty is obtained by dividing the uncertainty by the divisor.

5) Sensitivity coefficient is obtained directly from Formula 2.

6) The values have been rounded up to get conservative results.

Table 4 – Evaluation of uncertainty contribution due to the device under test for the measurement of the attenuation of an optical connection (u_{ref} excluded)

	Error source[1,2)]	Uncertainty[2)]		Probability distribution[3)]	Divisor[3)]	Standard uncertainty[4)]	Sensitivity coefficient[5)]	Uncertainty contribution
i	X_i	u (dB)	u (%)			$u(x_i)$ (%)	c_i	$u_i(y)$ (%)
7	u_{PDL}	0,01	0,23 %	rect	1,732 1	0,13 %	1.414	0,13 %
8	u_{mating}	0,05	1,16 %	rect	1,732 1	0,67 %	1	0,67 %
9	u_{ref}	0,1	2,33 %	rect	1,732 1	1,34 %	0	0 %
						$u_{DUT} = \sqrt{\sum_{i=7}^{9} u_i^2} =$		0,695 %

1) The uncertainty values listed in this table may vary as a function of the measurements laboratory, of the type of instrument used and as a function of measured DUT (for this example the DUT is a connection of Grade B connectors assembled on standard B1.3 single mode fibre, APC polished).

2) Definition of the error sources is the same as in 4.2. The errors have been estimated in dB's and were then transformed into a percentage for all further calculations.

3) Probability distributions are estimated for single measurements to be rectangular. For rectangular probability distributions the uncertainty has to be divided by $\sqrt{3} = 1,7321$.

4) Standard uncertainty is obtained by dividing the uncertainty by the divisor.

5) Sensitivity coefficient is obtained directly from Formula 2.

6) The values have been rounded up to get conservative results.

4.4 Combined and expanded uncertainty

The combined standard uncertainty can be calculated using Formula (6):

Table 5 – Evaluation of uncertainty contribution for the measurement of the attenuation of an optical connector against reference connector (u_{ref} included in u_{DUT})

	Error source	Sensitivity coefficient	Uncertainty contribution	
i	X_i	c_i	$u_i(y)$ (%)	$u_i(y)$ (dB)
1	u_{instr}	1	0,34 %	0,015 dB
2	u_{source}	1	0,19 %	0,008 dB
3	u_{DUT}	1	1,51 %	0,065 dB
$u_A = \sqrt{\sum_{i=1}^{3} u_i^2} =$			1,56 %	0,067 dB

NOTE the values have been rounded up to get conservative results.

Table 6 – Evaluation of uncertainty contribution for the measurement of the attenuation of an optical connection (u_{ref} excluded in u_{DUT})

	Error source	Sensitivity coefficient	Uncertainty contribution	
i	X_i	c_i	$u_i(y)$ (%)	$u_i(y)$ (dB)
1	u_{instr}	1	0,34 %	0,015 dB
2	u_{source}	1	0,18 %	0,008 dB
3	u_{DUT}	1	0,695 %	0,030 dB
$u_A = \sqrt{\sum_{i=1}^{3} u_i^2} =$			0,79 %	0,034 dB
NOTE The values have been rounded up to get conservative results.				

In Table 5 and Table 6 the contribution of the power meters, of the source and of the device under test are displayed separately as a percentage and in logarithmic scale.

The expanded uncertainty is

$$U_A = k \cdot u_A \tag{7}$$

where

k is the coverage factor.

For a coverage factor $k= 2$ (confidence level of approximately 95 %), the following values as shown in Table 7 are obtained

Table 7 – Expanded combined uncertainty

Expanded combined uncertainty		Remark
1,56 %	0,07 dB	Without uncertainty due to change of reference connector
3,12 %	0,14 dB	Including reference connector change uncertainty
NOTE The values have been rounded up to get conservative results.		

Annex A
(informative)

Uncertainty of measurements

A.1 General

Annex A summarises the form of evaluating, combining and reporting the uncertainty of measurement. It is based on ISO/IEC Guide 98-3:2008. It does not replace this guide that needs to be consulted for more advice.

This technical report 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 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:

$$s_{typeA} = \left[\frac{1}{m-1}\sum_{i=1}^{m}\left(y_i - y_{mean}\right)^2\right]^{1/2} \tag{A.2}$$

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

$$\sigma_{typeA} = \frac{s_r}{\sqrt{n}} \tag{A.3}$$

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 judgment 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.

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

If only upper and lower limit X_{max} and X_{min} can be estimated for the value of the quantity X (for example a manufacturer's specifications or a temperature range), a rectangular probability distribution is assumed, the estimated value is

$$x = \frac{1}{2}(X_{\text{max}} + X_{\text{min}}) \quad \text{(A.5)}$$

and the standard uncertainty is

$$u(x) = \frac{1}{2\sqrt{3}}(X_{\text{max}} - X_{\text{min}}) \quad \text{(A.6)}$$

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

$$u(y) = c \times u(x) \quad \text{(A.7)}$$

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.

$$c = \frac{\partial y}{\partial x} \quad \text{(A.8)}$$

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 Formula (A.8) 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:

$$u_{\text{c}}(y) = \sqrt{\sum_{i=1}^{n} u_i^2(y)} \quad \text{(A.9)}$$

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 the Formula (A.9). Despite its partially type A origin, uc 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 $uc(y)$ by a coverage factor k:

$$U = k \times u_c(y) \quad \text{(A.10)}$$

For a level of confidence of approximately 95 %, the default level, then k = 2. The above value for k is valid under some conditions, see ISO/IEC Guide 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)

The uncertainty budget for attenuation measurements

B.1 General

This analysis shows one possible implementation of the uncertainty budget for attenuation measurements, based on the principles as defined in ISO/IEC Guide 98-3:2008. Uncertainty calculations should preferably be performed using a linear representation of the measured quantities, as shown in this example. This analysis is also assuming that uncorrelated quantities are measured.

B.2 Mathematical aspects

The attenuation *A* can be expressed as the ratio of a reference power with a transmitted power level, according to

$$A = P_{out} / P_{in} \quad \text{(B.1a)}$$

$$A_{\text{dB}} = -10 \cdot \log(A) \quad \text{(B.1b)}$$

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

$$u_A{}^2 = \sum_{i=1}^{N} \left(\frac{\partial A}{\partial P_i} \right)^2 \cdot u_{P_i}{}^2 + 2 \cdot \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{\partial A}{\partial P_i} \cdot \frac{\partial A}{\partial Pj} \cdot u(P_i, P_j) \ . \quad \text{(B.2)}$$

u_{Pi} are the uncertainties related to the measurements of power levels *Pi* and $u(Pi,Pj)$ are the covariances. This example concentrates on a simple case with negligible correlations. This yields to the following simplified equation:

$$u_A{}^2 = \sum_{i=1}^{N} \left(\frac{\partial A}{\partial P_i} \right)^2 \cdot u_{P_i}{}^2 \ . \quad \text{(B.3)}$$

By calculating the partial derivatives, using Formula (B.1a) one gets:

$$u_A{}^2 = \sum_{i=1}^{N} \left(\frac{\partial A}{\partial P_i} \right)^2 \cdot u_{P_i}{}^2 = \left(\frac{\partial A}{\partial P_{out}} \right)^2 \cdot u_{Pout}{}^2 + \left(\frac{\partial A}{\partial P_{in}} \right)^2 \cdot u_{Pin}{}^2 = \left(\frac{1}{P_{in}} \right)^2 \cdot u_{Pout}{}^2 + \left(\frac{-P_{out}}{P_{in}{}^2} \right)^2 \cdot u_{Pin}{}^2 \quad \text{(B.4)}$$

It is common use to express the uncertainties u_{Pin} and u_{Pout} in a relative form, namely:

$u_{n\ Pin} = u_{Pin} / P_{in}$ and $u_{n\ Pout} = u_{Pout} / P_{out}$.

This can be achieved by dividing Formula (B.4) by A^2, namely:

$$\left(\frac{u_A}{A}\right)^2 = \left(\frac{P_{in}}{P_{out}}\right)^2 \cdot \left(\frac{1}{P_{in}}\right)^2 \cdot u_{Pout}{}^2 + \left(\frac{P_{in}}{P_{out}}\right)^2 \cdot \left(\frac{-P_{out}}{P_{in}{}^2}\right)^2 \cdot u_{Pin}{}^2 = \left(\frac{u_{Pout}}{P_{out}}\right)^2 + \left(\frac{u_{Pin}}{P_{in}}\right)^2 \quad \text{(B.5)}$$

This can be finally written as:

$$\left(\frac{u_A}{A}\right)^2 = u_{n_{Pin}}{}^2 + u_{n_{Pout}}{}^2 \quad \text{(B.6)}$$

The relative uncertainties $u_{n_{P_{in}}}$ and $u_{n_{P_{out}}}$ depend on a series of contributions, which can be expressed as

$$u_{n_{P_{in}}} = \sqrt{u_{abs_{Pin}}{}^2 + u_{TypeA_{Pin}}{}^2 + u_{P_{stab}}{}^2 + u_{PDL_{in}}{}^2 + u_{PDR_{in}}{}^2 + u_{Displ_{in}}{}^2} \quad \text{(B.7)}$$

$$u_{n_{P_{out}}} = \sqrt{u_{abs_{Pout}}{}^2 + u_{TypeA_{Pout}}{}^2 + u_{P_{stab}}{}^2 + u_{PDL_{out}}{}^2 + u_{PDR_{out}}{}^2 + u_{Displ_{out}}{}^2 + u_{Lin}{}^2 + u_{Unif}{}^2 + u_{Mating}{}^2 + u_{\mathrm{Re}\,f}{}^2} \quad \text{(B.8)}$$

where,

$u_{abs_{Pin}}, u_{abs_{Pout}}$ are the 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;

$u_{A_{Pin}}, u_{A_{Pout}}$ are the type A relative uncertainties in case of repeated measurements of P_{in} and of P_{out}, or are given by the relative repeatability ΔP_{rep} of the power meter in case of a single measurement, namely $u_{APi} = \Delta P_{rep} / \sqrt{3}$;

u_{Pstab} is the relative uncertainty arising from the stability of the optical source;

u_{PDR_i} is the relative uncertainty arising from the polarization dependency of the responsivity of power meter i;

u_{PDL_i} is the relative uncertainty arising from the polarization dependant losses of the fibre and of the connectors for the measurements of P_i *(i.e.* P_{in} and P_{out}*);*

u_{Displ_i} is the relative uncertainty arising from the finite display resolution of power meter i;

u_{Lin} is the 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}.;

u_{Unif} is the relative uncertainty arising from the uniformity of the power meter and from possible reflection effects between the detector and the ferrule. This contribution will only be relevant when performing reference and DUT measurements using the same power meter but with different illuminating conditions. This may be the case when using different connector types (for example PC and APC, or ferrules of different materials) for the two respective measurements;

$u_{\mathrm{Re}\,f}$ is the uncertainty due to the use of different reference connectors. This contribution is only relevant when measuring the attenuation of a single connector by comparison with a reference connector;

u_{Mating} is the relative uncertainty related to the repeatability of the connector mating.

This leads to the following formula:

$$\frac{u_A}{A} = \sqrt{\begin{aligned}&u_{abs_{Pin}}{}^2 + u_{TypeA_{Pin}}{}^2 + u_{P_{stab}}{}^2 + u_{PDL_{in}}{}^2 + u_{PDR_{in}}{}^2 + u_{Displ_{in}}{}^2 \\ &+ u_{abs_{Pout}}{}^2 + u_{TypeA_{Pout}}{}^2 + u_{P_{stab}}{}^2 + u_{PDL_{out}}{}^2 + u_{PDR_{out}}{}^2 + u_{Displ_{out}}{}^2 + u_{Lin}{}^2 + u_{Unif}{}^2 + u_{Mating}{}^2 + u_{\mathrm{Re}\,f}{}^2\end{aligned}} \quad \text{(B.9)}$$

By grouping the terms differently one gets:

$$\frac{u_A}{A} = \sqrt{\begin{aligned}&u_{abs_{Pin}}{}^2 + u_{TypeA_{Pin}}{}^2 + u_{abs_{Pout}}{}^2 + u_{TypeA_{Pout}}{}^2 + u_{PDR_{in}}{}^2 + u_{PDR_{out}}{}^2 + u_{Displ_{in}}{}^2 + u_{Displ_{out}}{}^2 + u_{Lin}{}^2 + u_{Unif}{}^2 \\ &+ 2 \cdot u_{P_{stab}}{}^2 \\ &+ u_{PDL_{in}}{}^2 + u_{PDL_{out}}{}^2 + u_{mating}{}^2 + u_{\mathrm{Re}\,f}{}^2\end{aligned}} \quad \text{(B.10)}$$

This formula can therefore be written as

$$\frac{u_A}{A} = \sqrt{u_{instr.}{}^2 + u_{source}{}^2 + u_{DUT}{}^2}\,, \quad \text{(B.11)}$$

where

$$\begin{aligned}u_{instr}{}^2 &= u_{abs\ \ Pin}{}^2 + u_{TypeA_{Pin}}{}^2 + u_{abs_{Pout}}{}^2 + u_{TypeA_{Pout}}{}^2 + u_{PDR_{in}}{}^2 + u_{PDR_{out}}{}^2 + u_{Displ_{in}}{}^2 + u_{Displ_{out}}{}^2 + u_{Lin}{}^2 + u_{Unif}{}^2 \\ u_{source}{}^2 &= 2 \cdot u_{P_{stab}}{}^2 \\ u_{DUT}{}^2 &= u_{PDL_{in}}{}^2 + u_{PDL_{out}}{}^2 + u_{mating}{}^2 + u_{\mathrm{Re}\,f}{}^2\end{aligned} \quad \text{(B.12)}$$

The combined expanded uncertainty will finally be given by

$$\frac{U_A}{A} = k \cdot \frac{u_A}{A} \quad \text{(B.13)}$$

where

k is the coverage factor.

The logarithmic value of the uncertainty will finally be calculated as follows:

$$\left(\frac{U_A}{A}\right)_{\mathrm{dB}} = 10 \cdot \log\left(\frac{U_A}{A} + 1\right). \quad \text{(B.14)}$$

B.3 Useful approximation

B.3.1 Low attenuation measurements

For low-level attenuations, A≈ 1 and Formula.(B.11) can be simplified as follows:

$$\frac{u_A}{A} \approx u_A = \sqrt{u_{instr.}{}^2 + u_{source}{}^2 + u_{DUT}{}^2} \quad \text{(B.15)}$$

B.3.2 Measurements of low attenuations performed with a single power meter

In this specific case, and assuming almost identical Polarisation Dependent Loss (PDL) values when measuring P_{in} and $P_{out,}$ the following assumptions can be made:

$u_{abs_{Pin}}$: not relevant

$u_{abs_{Pout}}$: not relevant

$$u_{TypeA_{Pin}} = u_{TypeA_{Pout}} = u_{TypeA}$$

$$u_{PDR_{in}} = u_{PDR_{out}} = u_{PDR}$$

$$u_{Displ_{in}} = u_{Displ_{out}} = u_{Displ}$$

Formulas (B.10), (B.13) and (B.14) can then be simplified as follows:

$$u_A \approx \sqrt{2 \cdot u_{TypeA}{}^2 + 2 \cdot u_{PDR}{}^2 + 2 \cdot u_{Displ}{}^2 + u_{Lin}{}^2 + u_{Unif}{}^2 + 2 \cdot u_{P_{stab}}{}^2 + 2 \cdot u_{PDL}{}^2 + u_{mating}{}^2 + u_{\mathrm{Re}\,f}{}^2} \quad \text{(B.16)}$$

$$U_A = k \cdot u_A \quad \text{(B.17)}$$

$$U_{A\mathrm{dB}} = 10 \cdot \log(U_A + 1) \quad \text{(B.18)}$$

Bibliography

IEC 61300-3 (all parts), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3: Examinations and measurements*

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch