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Application of uncertainty of measurement to conformity assessment activities in the electrotechnical sector

Application de l'incertitude de mesure aux activités d'évaluation de la conformité dans le secteur électrotechnique

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CONTENTS

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APPLICATION OF UNCERTAINTY OF MEASUREMENT TO CONFORMITY ASSESSMENT ACTIVITIES IN THE ELECTROTECHNICAL SECTOR

FOREWORD

This first edition of IEC Guide 115 has been prepared in accordance with Annex A of Part 1 of the ISO/IEC Directives by the IECEE/CTL.

The text of this guide is based on the following documents:

Approval document	Report on voting
C/1446/DV	C/1457/RV

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

INTRODUCTION

This Guide has been prepared by the IECEE Committee of Testing Laboratories (CTL) to provide guidance on the practical application of the measurement uncertainty requirements of ISO/IEC 17025 to the electrical safety testing conducted within the IECEE CB Scheme.

The IECEE CB Scheme is a multilateral, international agreement, among over 40 countries and some 60 national certification bodies, for the acceptance of test reports on electrical products tested to IEC standards.

The aim of the CTL is, among other tasks, to define a common understanding of the test methodology with regard to the IEC standards as well as to ensure and continually improve the repeatability and reproducibility of test results among the member laboratories.

The practical approach to measurement uncertainty outlined in this Guide has been adopted for use in the IECEE Schemes, and is also extensively used around the world by testing laboratories engaged in testing electrical products to national safety standards.

This guide is of particular interest to the following IEC Technical Committees which may decide to make use of it if necessary:

TECHNICAL COMMITTEE 13: EQUIPMENT FOR ELECTRICAL ENERGY MEASUREMENT, TARIFF AND LOAD CONTROL
TECHNICAL COMMITTEE 17: SWITCHGEAR AND CONTROLGEAR
TECHNICAL COMMITTEE 18: ELECTRICAL INSTALLATIONS OF SHIPS AND OF MOBILE AND FIXED OFFSHORE UNITS
TECHNICAL COMMITTEE 20: ELECTRIC CABLES
TECHNICAL COMMITTEE 21: SECONDARY CELLS AND BATTERIES
TECHNICAL COMMITTEE 22: POWER ELECTRONIC SYSTEMS AND EQUIPMENT
TECHNICAL COMMITTEE 23: ELECTRICAL ACCESSORIES
TECHNICAL COMMITTEE 32: FUSES
TECHNICAL COMMITTEE 33: POWER CAPACITORS
TECHNICAL COMMITTEE 34: LAMPS AND RELATED EQUIPMENT
TECHNICAL COMMITTEE 35: PRIMARY CELLS AND BATTERIES
TECHNICAL COMMITTEE 38: INSTRUMENT TRANSFORMERS
TECHNICAL COMMITTEE 39: ELECTRONIC TUBES
TECHNICAL COMMITTEE 40: CAPACITORS AND RESISTORS FOR ELECTRONIC EQUIPMENT
TECHNICAL COMMITTEE 47: SEMICONDUCTOR DEVICES
TECHNICAL COMMITTEE 59: PERFORMANCE OF HOUSEHOLD ELECTRICAL APPLIANCES
TECHNICAL COMMITTEE 61: SAFETY OF HOUSEHOLD AND SIMILAR ELECTRICAL APPLIANCES
TECHNICAL COMMITTEE 62: ELECTRICAL EQUIPMENT IN MEDICAL PRACTICE
TECHNICAL COMMITTEE 64: ELECTRICAL INSTALLATIONS AND PROTECTION AGAINST ELECTRIC SHOCK
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TECHNICAL COMMITTEE 82: SOLAR PHOTOVOLTAIC ENERGY SYSTEMS

APPLICATION OF UNCERTAINTY OF MEASUREMENT TO CONFORMITY ASSESSMENT ACTIVITIES IN THE ELECTROTECHNICAL SECTOR

1 Scope

This Guide presents a practical approach to the application of uncertainty of measurement to conformity assessment activities in the electrotechnical sector . It is specifically conceived for use in IECEE Schemes as well as by testing laboratories engaged in testing electrical products to national safety standards. Clause 4 describes the application of uncertainty of measurements principles. Clause 5 provides guidance on making uncertainty of measurement calculations. Annex A gives some examples relating to uncertainty of measurement calculations for product conformity assessment testing.

2 Reference documents

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

Guide to the expression of uncertainty in measurement (GUM) (1995)
[BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML]

International vocabulary of basic and general terms in metrology (VIM) (1996)
[BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML]

3 Terms and definitions

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

3.1
coverage factor
number that, when multiplied by the combined standard uncertainty, produces an interval (the expanded uncertainty) about the measurement result that may be expected to encompass a large, specified fraction (e.g. 95 %) of the distribution of values that could be reasonably attributed to the measurand

3.2
combined standard uncertainty
result of the combination of standard uncertainty components

3.3
error of measurement
result of a measurement minus a true value of the measurand (not precisely quantifiable because true value lies somewhere unknown within the range of uncertainty)

3.4
expanded uncertainty
obtained by multiplying the combined standard uncertainty by a coverage factor

3.5
level of confidence
probability that the value of the measurand lies within the quoted range of uncertainty

3.6
measurand
quantity subjected to measurement, evaluated in the state assumed by the measured system during the measurement itself

[IEC 60359:2001]

3.7
quantity X_i
source of uncertainty

3.8
standard deviation
positive square root of the variance

3.9
standard uncertainty
estimated standard deviation

3.10
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

[IEC 60359:2001, modified]

3.11
type A evaluation method
method of evaluation of uncertainty of measurement by the statistical analysis of series of observations

3.12
type B evaluation method
method of evaluation of uncertainty of measurement by means other than the statistical analysis of series of observations

4 Application of uncertainty of measurement principles

4.1 General

4.1.1 Qualification and acceptance of CB test laboratories (CBTL), e.g. in the IECEE, is performed according to IEC/ISO 17025, which states in 5.4.6.2:

> "Testing laboratories shall have and apply procedures for estimating uncertainty of measurement. In certain cases, the nature of the test method may preclude rigourous, metrologically and statistically valid, calculation of uncertainty of measurement. In these cases the laboratory shall at least attempt to identify all the components of uncertainty and make a reasonable estimation, and shall ensure that the form of reporting of the result does not give a wrong impression of the uncertainty. Reasonable estimation shall be based on knowledge of the performance of the method and on the measurement scope and shall make use of, for example, previous experience and validation data.
>
> **NOTE 1 The degree of rigour needed in an estimation of uncertainty of measurement depends on factors such as:**
>
> - **the requirements of the test method;**
> - **the requirements of the client;**
> - **the existence of narrow limits on which decisions on conformance to a specification are based.**
>
> **NOTE 2 In those cases where a well-recognized test method specifies limits to the values of the major sources of uncertainty of measurement and specifies the form of presentation of calculated results, the laboratory is considered to have satisfied this clause by following the test method and reporting instructions (see 5.10)."**

4.1.2 IEC/ISO 17025, 5.10.3.1, item c), states:

"Subclause 5.10.3.1 includes the following:

c) where applicable, a statement on the estimated uncertainty of measurement; information on uncertainty is needed in test reports, when it is relevant to the validity of application of the test results, when a client's instruction so requires, or when the uncertainty affects compliance to a specification limit."

4.1.3 IEC/ISO 17025 was written as a general use document, for all industries. Uncertainty of measurement principles are applied to laboratory testing and presentation of test results to provide a degree of assurance that decisions made about conformance of the products tested according to the relevant requirements are valid. Procedures and techniques for uncertainty of measurement calculations are well established. This CB Testing Laboratory (CBTL) procedure is written to provide more specific guidance on the application of uncertainty of measurement principles to reporting of testing results under the CB Scheme.

4.1.4 This clause of CBTL procedure focuses on the application of uncertainty of measurement principles under the CB Scheme, while, Clause 5 of CBTL procedure provides guidance on making uncertainty of measurement calculations and includes examples.

4.2 Uncertainty of measurement principles

4.2.1 A challenge to applying uncertainty of measurement principles to conformity assessment activities is managing the cost, time and practical aspects of determining the relationships between various sources of uncertainty. Some relationships are either unknown or would take considerable effort, time and cost to establish. There are a number of proven techniques available to address this challenge. These techniques include eliminating from consideration those sources of variability, which have little influence on the outcome and minimizing significant sources of variability by controlling them.

4.3 Background

4.3.1 Test methods used under the IECEE CB Scheme are in essence consensus standards. Criteria used to determine conformance with requirements are most often based on a consensus of judgment of what the limits of the test result should be. Exceeding the limit by a small amount does not result in an imminent hazard. Test methods used may have a precision statement expressing the maximum permissible uncertainty expected to be achieved when the method is used. Historically, test laboratories have used state-of-the-art equipment and not considered uncertainty of measurement when comparing results to limits. Safety standards have been developed in this environment and the limits in the standards reflect this practice.

4.3.2 Test parameters that influence the results of tests can be numerous. Nominal variations in some test parameters have little effect on the uncertainty of the measurement result. Variations in other parameters may have an effect. However, the degree of influence can be minimized by limiting the variability of the parameter when performing the test.

4.3.3 A frequent way of accounting for the effects of test parameters on tests results is to define the acceptable limits of variability of test parameters. When this is done, any variability in measurement results obtained due to changes in the controlled parameters is not considered significant if the parameters are controlled within the limits. Examples of the application of this technique require:

a) input power source to be maintained: voltage ±2 %, frequency ±0,5 %, total harmonic distortion maximum 3 %;

b) ambient temperature: 23 °C ± 2 °C;

c) relative humidity: 93 % ± 2 % (RH);

d) personnel: documented technical competency requirements for the test;

e) procedures: documented laboratory procedures;

f) equipment accuracy: instrumentation with accuracy according to CTL decision 251A.

NOTE The acceptable limits in items a) through c) are given as examples and do not necessarily represent actual limits established.

4.3.4 The end result of controlling sources of variability within prescribed limits is that the measurement result can be used as the best estimate of the measurand. In effect, the uncertainty of measurement about the measured result is negligible with regard to the final pass/fail decision.

4.4 Uncertainty of measurement principles – Application of procedures

4.4.1 When a test results in measurement of a variable, there is uncertainty associated with the test result obtained

4.4.2 Procedure 1, see Figure 1, is used when calculation of uncertainty of measurement is required by IEC/ISO 17025, 5.4.6.2 and 5.10.3.1 item c). Calculate the uncertainty for measurement (see Clause 5) and compare the measured result with the uncertainty band to a defined acceptable limit. The measurement complies with the requirement if the probability of its being within the limit is at least 50 %.

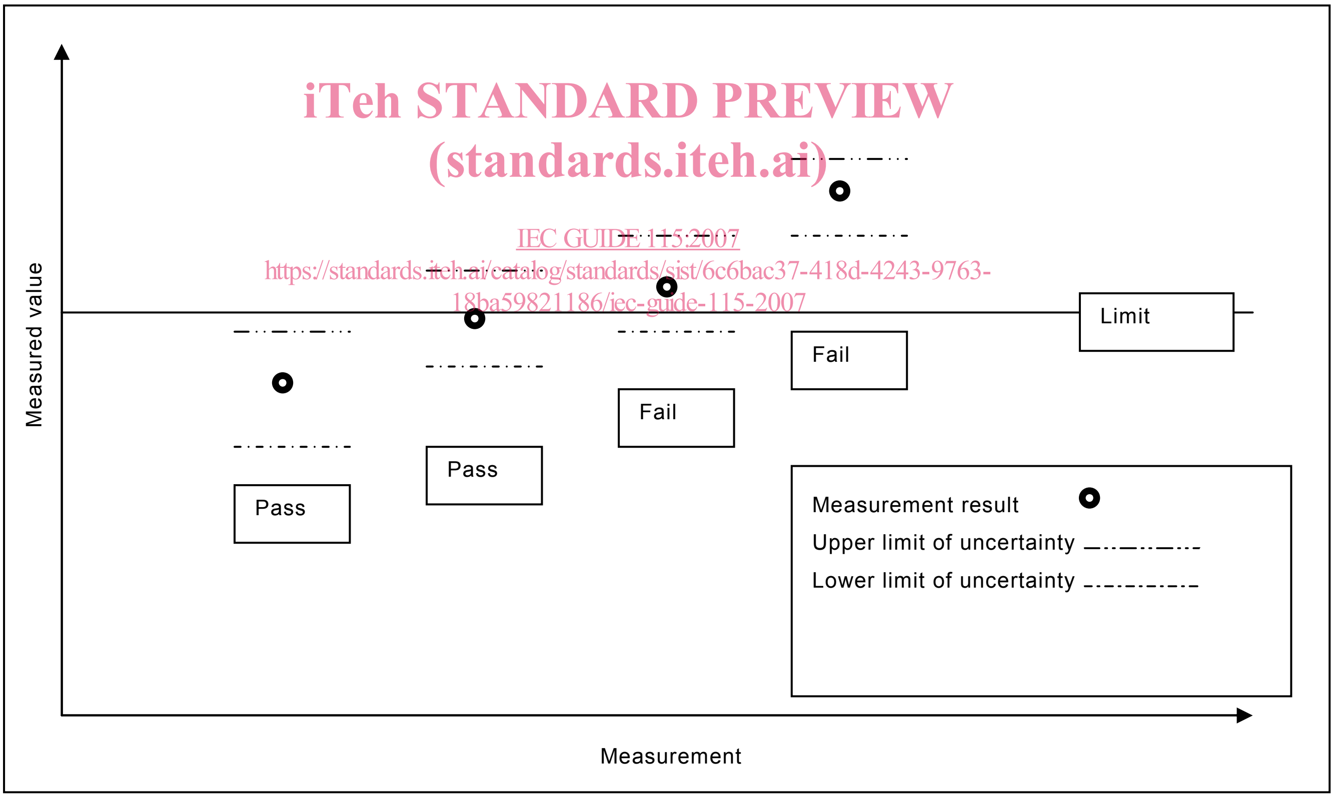

Figure 1 – Procedure 1: uncertainty of measurement calculated

4.4.3 Procedure 2, see Figure 2, is used when IEC/ISO 17025, 5.4.6.2, Note 2, applies. Procedure 2 is the traditional method used under the CB Scheme and has been referred to as the "accuracy method". The test performed is routine. Sources of uncertainty are minimized so that the uncertainty of the measurement need not be calculated to determine conformance with the limit. Variability in test parameters is within acceptable limits. Test parameters such as power source voltage, ambient temperature and ambient humidity are maintained within the defined acceptable limits for the test. Personnel training and laboratory procedures minimize uncertainty of measurement due to human factors. Instrumentation used has an uncertainty within prescribed limits.

NOTE The name, accuracy method, comes from the concept of limiting uncertainty due to instrumentation by using instruments within prescribed accuracy limits. For this purpose, the accuracy specification for an instrument is considered the maximum uncertainty of measurement attributable to the instrument.

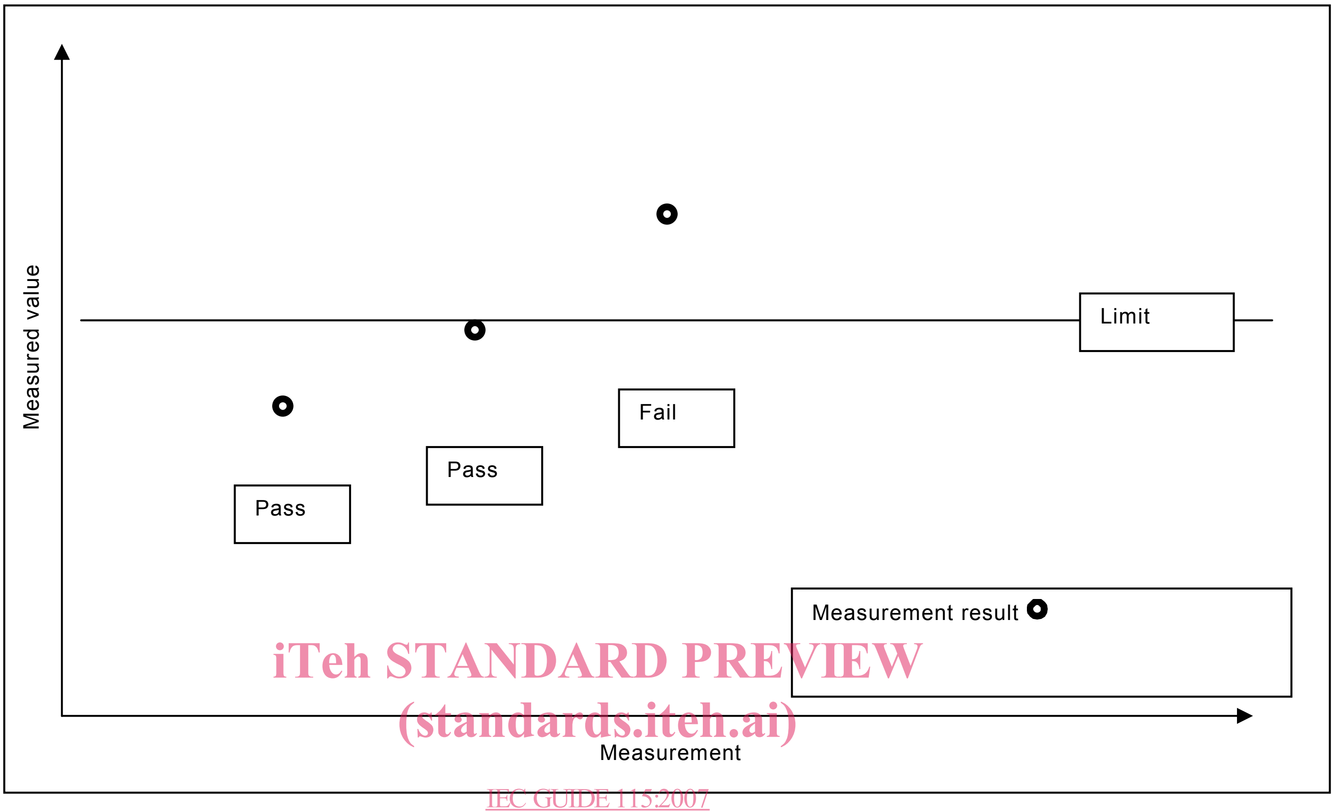

Figure 2 – Procedure 2: accuracy method

4.4.4 The measurement result is considered in conformance with the requirement if it is within the prescribed limit. It is not necessary to calculate the uncertainty associated with the measurement result.

4.4.5 Example – Procedure 2

- Power supply output voltage measurement test

  a) Method

  Connect the power supply to a mains source of rated voltage, ±2 %, and rated frequency. Measure output voltage from power supply while loaded to rated current, ±2 %, with a non-inductive resistive load. The test is to be performed in an ambient temperature of 23 °C ± 2 °C.

  Use metres having an accuracy conforming to CTL decision 251A.

  The power supply conforms to the requirements if the output voltage is ±5 % of rated value.

  b) Results

  Power supply rating: 240 V, 50 Hz input; 5 V d.c., 2 A output.

Input		**Output**	
U V	**Frequency** Hz	I A	U V
242	50	2,01	5,1

Test ambient temperature: 24 °C.

The accuracy of the instruments used is shown in the following table:

Metre	**Calibrated accuracy for scale used for measurement**	**CTL decision 251A, max.**
Thermometer	±1,0 °C	±2,0 °C
Voltmeter	±0,5 %	±1,5 %
Frequency	±0,2 %	±0,2 %
Current	±0,5 %	±1,5 %

The conclusion of the test is that the power supply conforms to the requirement.

4.5 Conclusion

4.5.1 The traditional approach to addressing uncertainty of measurement for conformity assessment activities under the CB Scheme, has been the application of the accuracy method. This method minimizes sources of uncertainty associated with the performance of routine tests so that the measurement result can be directly compared with the test limit to determine conformance with the requirement. This method conforms to the requirements in IEC/ISO 17025. The accuracy method takes less time and costs less to implement than detailed uncertainty of measurement calculations and the conclusions reached are valid with regard to the final pass/fail decision.

4.5.2 In situations where the traditional, accuracy method does not apply, uncertainty of measurement values are calculated and reported along with the variables results obtained during testing.

5 Guidance on making uncertainty of measurement calculations including examples of how to perform the calculations

5.1 General principles

5.1.1 This clause is meant to be a short and simplified summary of the steps to be taken by a CBTL when the need to estimate uncertainties arises. It also includes examples of how to perform the calculations.

5.1.2 It is by no means a comprehensive paper about measurement uncertainty (MU), its sources and estimation in general, but is supposed to offer a practical approach for most applicable circumstances within a CBTL in the IECEE CB Scheme.

5.1.3 No measurement is perfect and the imperfections give rise to error of measurement in the result. Consequently, the result of a measurement is only an approximation to the measured value (measurand) and is only complete when accompanied by a statement of the uncertainty of that approximation. Indeed, because of measurement uncertainty, a true value can never be known.

5.1.4 The total uncertainty of a measurement is a combination of a number of component uncertainties. Even a single instrument reading may be influenced by several factors. Careful consideration of each measurement involved in the test is required to identify and list all the factors that contribute to the overall uncertainty. This is a very important step and requires a good understanding of the measuring equipment, the principles and practice of the test and the influence of environment.

5.1.5 The Guide to the expression of uncertainty in measurement (GUM) has adopted the approach of grouping uncertainty components into two categories based on their method of evaluation, Type A and Type B. This categorization of the methods of evaluation, rather than of the components themselves, avoids certain ambiguities.

5.1.6 Type A evaluation is carried out by calculation from a series of repeated observations, using statistical methods.

5.1.7 Type B evaluation is carried out by means other than that used for Type A. For example, by judgment based on the following table.

Data in calibration certificates	This enables corrections to be made and type B uncertainties to be assigned
Previous measurement data	For example, history graphs can be constructed and yield useful information about changes with time
Experience with or general knowledge	Behaviour and properties of similar materials and equipment
Accepted values of constants	Associated with materials and quantities
Manufacturers' specifications	
All other relevant information	

5.1.8 Individual uncertainties are evaluated by the appropriate method and each is expressed as a standard deviation and is referred to as a standard uncertainty.

5.2 Summary of steps when estimating uncertainty

5.2.1 Identify the factors that may significantly influence the measured values and review their applicability. There are many possible sources in practice, mainly including.

a) Contribution from calibration of the measuring instruments, including contribution from reference or working standards.

b) Temperature error at the beginning and end of a test (e.g. winding resistance method).

c) Uncertainty related to the loading applied and the measurement of it.

d) Velocity of air flow over the test sample and uncertainty in measuring it.

e) For digital instruments, there are the number of displayed digits and the stability of the display at the time the reading is taken. In addition, the reported uncertainty of an instrument does not necessarily include the display.

f) Instrument resolution, limits in graduation of a scale.

g) Approximations and assumptions incorporated in the measurement method.

h) Uncertainty due to the procedures used to prepare the sample for test and actually testing it.

i) If a computer is used to acquire the readings from the instrument, there is uncertainty associated with the processing of the data due to calculations or other manipulations within the computer such as analog to digital conversions, and conversions between floating point and integer numbers.

k) Rounded values of constants and other parameters used for calculations.

m) Effects of environmental conditions (e.g. variation in ambient temperature) or measurement of these on the measurement.

   --> Negligible in case environmental conditions are stable (*assumed and expected from a CBTL*).

n) Variability of the power supply source (voltage, current, frequency) the sample is connected to and the uncertainty in measuring it.

   --> Negligible in case stabilized supply sources are used (*assumed and expected from a CBTL*).

o) Personal bias in reading analogue instruments

   (e.g. parallax error or the number of significant figures that can be interpolated).

   --> Negligible in case of digital displays or in case of appropriate training (assumed and expected from a CBTL).

p) Variation between test samples and in case the samples are not fully representative.

Unless the IEC standard specifies tests on multiple samples, only one sample is tested.

--> The variation between test samples is assumed to be negligible by CBTLs

NOTE This list does not state all of the items that can contribute to MU. Other factors may have to be identified and considered by each laboratory respectively.

5.2.2 Transform influencing factors x_i to the unit of the measured value (quantify), for which you are going to estimate the uncertainty, if not already given in that unit (e.g. if the unit of the measured value is V and a resistor's tolerance in Ω is one of the influencing factors, transform the change of resistance to the resulting contribution in V).

Once the uncertainty contributions associated with a measurement process have been identified and quantified, it is necessary to combine them in some manner in order to provide a single value of uncertainty that can be associated with the measurement result.

5.2.3 Determine the probability distribution

The probability distribution of the measured quantity describes the variation in probability of the true value lying at any particular difference from the measured or assigned result. The form of the probability distribution will often not be known, and an assumption has to be made, based on prior knowledge or theory, that it approximates to one of the common forms. It is then possible to calculate the standard uncertainty, $U(x_\mathrm{i})$, for the assigned form from simple expressions. The four main distributions of interest are

- normal;
- rectangular;
- triangular;
- U-shaped.

5.2.4 Normal distribution is assigned when the uncertainty is taken from, for example, a calibration certificate/report where the coverage factor, *k*, is stated. The standard uncertainty is found by dividing the stated uncertainty from the calibration certificate by its coverage factor *k*, which is *k* = 2 for a level of confidence of approximately 95 % (recommended for CBTL in the IECEE CB scheme). It may be necessary to confirm *k* with the calibration laboratory in case it is not stated on the certificate.

$$\text{Normal: } u(x_i) = \frac{\text{uncertainty}}{k}$$

5.2.5 Rectangular distribution means that the probability density is constant within the prescribed limits. A rectangular distribution should be assigned where a manufacturer's specification limits are used as the uncertainty, unless there is a statement of confidence associated with the specification, in which case a normal distribution can be assumed.

$$\text{Rectangular: } u(x_i) = \frac{a_i}{\sqrt{3}}$$

where a_i is the half width of the rectangular distribution.

5.2.6 U-shaped distribution is applicable to mismatch uncertainty. The value of the limit for the mismatch uncertainty, M, associated with the power transfer at a junction is obtained from

$$100\,((1 \pm |\Gamma_G|\,|\Gamma_L|)^2 - 1)\,\% \ \text{ or } \ 20\ \log_{10}\ (1 \pm |\Gamma_G|\,|\Gamma_L|)\ \text{dB} \ \text{ (logarithmic units)}$$

where Γ_G and Γ_L are the reflection coefficients for the source and load.

The mismatch uncertainty is asymmetric about the measured result; however, the difference this makes to the total uncertainty is often insignificant, and it is acceptable to use the larger of the two limits.

U-shaped distribution is used for EMC purposes but also for climatic control of temperature and humidity.

U-shaped: $u(x_i) = \frac{M}{\sqrt{2}}$

5.2.7 Triangular distribution means that the probability of the true value lying at a point between two prescribed limits increases uniformly from zero at the extremities to the maximum at the centre. A triangular distribution should be assigned where the contribution has a distribution with defined limits and where the majority of the values between the limits lie around the central point.

Triangular: $u(x_i) = \frac{a_i}{\sqrt{6}}$

5.2.8 A detailed approach to the determination of probability distribution can be found in the Guide to the expression of uncertainty in measurement (GUM).

5.2.9 Correlation: For the statistical approach to the combination of individual uncertainty contributions to be valid, there shall be no common factors associated with these contributions.

5.2.10 The effect of correlated input quantities may be to increase or decrease the combined standard uncertainty. For example, if the area of a rectangle is determined by measurement of its width and height using the same measuring implement the correlation will increase the uncertainty. On the other hand, if a gauge block were to be measured by comparison with another of identical material, the effect of uncertainty due to temperature will depend on the difference in temperature between the two blocks and will therefore tend to cancel.

5.2.11 If the correlation is such that the combined standard uncertainty is increased, the most straightforward approach is to add the standard uncertainties for these quantities before combining the result statistically with other contributions.

5.2.12 If, however, the correlation is such that the combined standard uncertainty will be decreased, as in the gauge-block comparison above, the difference in standard uncertainty would be used as the input quantity.

5.2.13 A detailed approach to the treatment of correlated input quantities can be found in the GUM.

5.2.14 Establish the uncertainty budget m_x, containing the standard uncertainties of each influencing factor (quantity) $u(x_i)$. Usually $u(x_i)$ will already represent the uncertainty contribution $u_i(y)$ of each factor. A convenient way to do that is to write the identified and potential contributing factors and their estimates into a table (see examples). The uncertainty contribution $u(m_x)$ is calculated by the formula:

$u(m_x) = \text{SQRT}\ (u_1(y)^2 + u_2(y)^2 + \ldots + u_i(y)^2\ )$

5.2.15 Calculate the expanded uncertainty U, considering your level of confidence. The expanded uncertainty is calculated by multiplying the standard uncertainty with the coverage factor k, which is $k = 2$ for a level of confidence of approximately 95 % (recommended for CBTL in the IECEE CB scheme), or $k = 3$ for approximately 99,7 % level of confidence.

$u = k \times u(m_x)$