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EUROPEAN COMPUTER MANUFACTURERS ASSOCIATION

STANDARD ECMA-181

UNCERTAINTY OF MEASUREMENT AS APPLIED TO TYPE APPROVAL OF PRODUCTS

December 1992

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Brief history

ECMA TC12 started work on the uncertainty of measurement and its effect on test laboratories, certification bodies and standards organisations in 1991. Largely independently, work also commenced in TC20 in the same time-frame. This document combines the work of both of these technical committees.

Type-test standards have been used for many years as a mechanism for determining whether a product meets a set of agreed requirements. The use of internationally agreed standards has played a major part in eliminating technical barriers to trade.

As type-test standards rely on comparing measured values with defined limits, the universal acceptance of results relies upon a common understanding of the measurement requirements. Hence, type-test standards frequently prescribe test methods. Even when using such test methods, the actual measurement made will have an associated uncertainty value.

The extent to which this uncertainty of measurement is firstly determined during measurement, and subsequently considered during type approval certification, may affect whether a product is deemed to have passed or failed a particular requirement. Complete elimination of technical barriers to trade are hence reliant upon a common approach to uncertainty of measurement.

A thorough treatment of measurement uncertainty requires both detailed analysis of the test arrangement coupled to detailed mathematical analysis. Such matters are being considered by ISO-TAG4-WG3 and ISO-TC69-SC6-WG3, amongst others. It is considered that this level of detail is unnecessary and inappropriate when considering the type-testing of products. The approach described here addresses the need to make measurements with a known uncertainty within the context of running a type-test laboratory, and is based on practical experience.

This document describes a minimum standard for test laboratories in regard to uncertainty of measurement, and how in turn this uncertainty of measurement should be treated by organisations involved in product certification. The principles described may be applied to the production of type-test standards.

Adopted as an ECMA Standard by the General Assembly of December 1992.

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1 Scope

This Standard specifies requirements intended to ensure that measurement uncertainty is considered and applied in a uniform manner.

This Standard is applicable to:

- Test Laboratories, who conduct type-tests in accordance with defined standards, and subsequently produce test reports, and
- Certification Organisations, who use the type-test results as a basis for issuing a certificate of conformity, and
- Standards Bodies, who produce type-test standards and correspondingly define type-test

The "Test Laboratories", Certification Organisations" and "Standards Bodies" may be:

- first party suppliers, in a contract,
- second parties purchasers, in a contract, or
- third parties independent, of a contract .

NOTE 1
As may be seen from the above description, there is a clear distinction made between the responsibilities of laboratories and certification organisations. This distinction is in accordance with the ISO/IEC Guides and EN 45000 series of standards.

2 Conformance

The requirements of this standard shall be incorporated into documentation appropriate to the organisation concerned in such a way that conformance is demonstrable and effective. Conformance is checked by review of the organisation's documentation and practices.

NOTE 2
Examples of appropriate documentation are, for:

- *Test Laboratories; incorporation into the quality manual and test procedures, however so named*
- *Certification Bodies; incorporation into the quality manual and qualification procedures, however so named.*
- *Standards Bodies; incorporation into guidelines to be followed by technical committees.*

It is normally permitted for the requirements of this standard to be excluded by contract.

3 References

The following publications were referenced when writing this standard:

ECMA 129	Safety of Information Technology Equipment ITE
EN 45001 / BS 7501	General criteria for the operation of testing laboratories
NAMAS Information Sheet NIS 20	Uncertainties of Measurement for NAMAS Electrical Product Testing Laboratories.
NAMAS Information Sheet NIS 3003	The Expression of Uncertainty and Confidence in Measurements.

4 Definitions

For the purpose of this ECMA Standard the following definitions apply.

4.1 Uncertainty of measurement

A statement of the limits of the range within which the true value of a measurement is expected to lie in relation to the recorded result and it must include the probability of the true value lying within these limits. This probability is termed the "confidence level".

NOTE 3
A complete expression for a measured voltage, say, in an acceptable form, would be: 10,35 V ± 0,05 V estimated confidence level 95 %.

4.2 Confidence level

The probability that the true value will lie within a defined range of values. The rules governing its evaluation depend upon the assumed or measured distribution of values.

4.3 Systematic uncertainty

A well defined quantity, usually a function of the measurement(s) being set up.

NOTE 4
Examples of systematic uncertainties are:

- *errors in graduation of a scale (eg the intervals between the calibrated points of a thermometer);*
- *uncertainty due to use of an instrument under constant conditions, but different from the conditions of calibration (e.g. at different temperature, or a thermometer in a liquid at different immersion from calibration);*
- *uncertainty of the current value of a standard or other significant component, or in its estimation from calibration history;*
- *calibration uncertainties.*

4.4 Random uncertainty

A quantity that is usually difficult to define, and usually outside the control of the experimenter.

NOTE 5
Examples of random uncertainties are:

- *variability resulting from imprecise definition of the test, for example:*
  - *poor accessibility in measuring length of a contour;*
  - *uncertain contact or adhesion of a (thermal) sensor;*
  - *ill defined potential terminals of a low valued resistor or capacitor;*
- *uncertainty in discrimination, such as:*
  - *setting a pointer to a fiducial mark on a scale;*
  - *interpolation between marked points on an analogue scale;*
  - *digitising error. ± 1 least significant digit (LSD) of a digital instrument (half LSD for reading, plus half LSD for zero);*
- *random fluctuations, such as:*
  - *slow random changes in the output of a calibrator to other voltage source (i.e. very low frequency noise);*
  - *fluctuation of any influence parameter which has not been, or cannot readily be, controlled, eg temperature of a resistance standard, or (more rarely) the atmospheric pressure to which it is subject.*

5 Acronyms

NAMAS National Measurement Accreditation Service
NOTE 6
The UK National unified accreditation service for testing and calibration laboratories. It is part of the UK government Department for Trade and Industry.

RMS Root mean square
RSS Root sum of squares

6 Total uncertainty of measurement

There are many factors which can introduce uncertainty into a particular measurement. Such uncertainties can either be systematic or random in nature. Further uncertainties are introduced due to the coupling of the measuring instrument to the equipment to be measured, these in turn can either be systematic and/or random. In order to determine a value of the total uncertainty of measurement within a particular confidence limit it is necessary to combine all the individual uncertainty factors.

NOTE 7
Examples of coupling uncertainties are:

- *loading effects, for example:*
  - *electrical loading, when performing a voltage measurement, due to the meter's internal impedance c.f. circuit impedance;*

  - *thermal loading, when performing temperature measurements, due to the thermal mass and conductivity of the thermocouple leads c.f. thermal mass of device under test;*
  - *mechanical loading, when performing acceleration measurements, due to the inertia of the accelerometer c.f. mass of object under test;*
- *electrical noise;*
  - *common mode;*
  - *differential mode;*
- *non-ideal waveforms;*
  - *non-sinusoidal voltage. Fourier analysis of the waveform may show that a significant proportion of the amplitude content is outside the chosen instrument's frequency specification;*
  - *"peaky" waveform. This may extend instrument beyond specification for crest factor (for an rms volt / current meter), or may otherwise overload instrument.*

Both systematic and random uncertainties usually follow one of two Population Distributions, Rectangular and Gaussian distributions, the latter being the most commonly used. As both random and systematic uncertainties usually obey a Gaussian distribution, only this will be considered in this Standard.

NOTE 8
In general, the Rectangular distribution gives a higher confidence level for a value of uncertainty and, as a consequence, the rectangular distribution is assumed where no information is known about the distribution of data being summed. The practical result of this is that, by assuming a rectangular distribution, there is a higher confidence that the final uncertainty quoted will encapsulate all possible measurement values.

7 Uncertainty of metering and gauging

Many of the factors described in clause 6 affect the uncertainty of metering and gauging:

- traceability of calibration;
- basic meter or gauge uncertainty;
- combined meter uncertainty.

In all cases, the stated total uncertainty of metering shall have a minimum estimated confidence level of 95 %.

NOTE 9
The term "Uncertainty of metering and gauging" is used since the requirements apply to both measuring instruments and to gauges.

For the purpose of this Standard, where

- components and test fixtures are specified in the type-test standard; and
- the value of these is critical to the accurate determination of test results, then

these components/test fixtures shall be treated as though they were a meter/gauge in respect of uncertainty.

NOTE 10
Examples of:
- *Components:*
  - *resistors used a current shunts in combination with a voltmeter;*
  - *resistors and capacitors used as part of a network having defined impedance/vs frequency characteristic.*
- *Test fixtures:*
  - *mechanical jig or fixture having dimensions designed to simulate a human ear;*
  - *energy sources which have a specified characteristic when loaded.*

Such components or test fixtures are often used in conjunction with meter/gauges.

Throughout this standard it is assumed that the limits of uncertainty are symmetrically displaced around the measured value.

NOTE 11
Uncertainty of metering and gauging is a contributory factor within the wider context of total uncertainty of measurement.

7.1 Traceability of calibration, (±) U_c

The uncertainty value specified on the calibration certificate.

NOTE 12

Test equipment is calibrated by comparison with a reference standard, which is ultimately traceable back to the national standard. Even national standards have uncertainties associated with them. Each step between the national standard and the reference standard adds uncertainty. Hence, U_c, will be the cumulative uncertainty of factors such as:

- *the reference instrument used by the calibration laboratory;*
- *the number of steps between this instrument and the national standard; and*
- *the national standard itself.*

7.2 Basic meter or gauge accuracy, (±) U_{mg}

The accuracy, as specified by the measuring instrument, and/or gauge, manufacturer; as applicable to the calibration interval used. For meters, this quantity typically varies with the percentage of range.

NOTE 13

For analogue electrical instruments this is usually given as a single value of ± x % of full scale deflection. For digital instruments it is typically given as ± (y % of reading plus "d" least significant digits) or ± (y % of reading plus x % of full scale deflection), in either of these cases an overall single figure uncertainty value (U_{mg}) shall be derived.

7.3 Total uncertainty for a single meter or gauge, (±) U_{ts}

The RSS addition of the uncertainties for a single meter/gauge.

Providing the uncertainties are symmetrical about the measured value, the total uncertainty of metering and gauging for a single instrument, U_{ts}, is given by:

$$(\pm)U_{ts} = \sqrt{{U_c}^2 + {U_{mg}}^2}$$

7.4 Total uncertainty for a combination of meters or gauges, (±) U_{tc}

The RSS addition of the uncertainties for a combination of meters/gauges.

Providing the uncertainties are symmetrical, the total uncertainty of metering and gauging for a combination of "n" instruments, U_{tc}, each having an individual uncertainty of U_{ts1}, U_{ts2}, ... U_{tsn} is given by:

$$(\pm)U_{tc} = \sqrt{{U_{ts\,1}}^2 + {U_{ts\,2}}^2 + \ldots + {U_{ts\,n}}^2}$$

NOTE 14

An example of combined meter uncertainty is the measurement of current using a shunt having an uncertainty of $\pm U_{ts1}$ in combination with a voltmeter having an uncertainty of $\pm U_{ts2}$.

8 Testing laboratory

8.1 General

The requirements in this section pertain to laboratories who perform type tests. Type tests typically compare a sample product with detailed requirements contained within a standard. Standards employ:

- set points, or a set range, which prescribe the conditions of test; and
- limit values, or a limit band, which prescribe the pass/fail criteria for a given result.

Uncertainty of measurement must be taken into account when setting the conditions for test, when comparing results with limit values, and when reporting results.

Laboratories are required to determine the uncertainty of metering and gauging, as described in 7. Laboratories are not required to determine the total uncertainty of measurement, as described in 7.3 and 7.4. Each test laboratory shall have available the value of the uncertainty of metering and gauging for each item of test equipment used to set defined parameters or measure values which determine conformity.

8.2 Requirement for maximum uncertainty of metering and gauging

Except where permitted, all measuring instruments, meters and gauges shall be selected and calibrated so that the uncertainty, as described in 6, does not exceed the appropriate value given in annex A. It is permitted to use meters and gauges with uncertainties exceeding the appropriate value given in annex A only where such a use would not alter the reported compliance result (per 8.4.2), and where the result is not within the uncertainty limit described in annex A.

NOTE 15
Annex A defines a set of minimum criteria. It is recommended to use test equipment with the lowest value of uncertainty available, especially when the measured value falls within the permitted range of uncertainty, given in annex A.

NOTE 16
The use of meters and gauges which exceed the uncertainty values described in annex A leads to the reported result being compared with limits which are more stringent than those specified in the type-test standard. Refer to 8.4.2 and 9.2.

Per 7, where component or test fixture tolerances are not specified in the type-test standard, the limits of uncertainty of metering and gauging described in annex A shall be used. An exception is that, for electrical components, the permitted tolerance is doubled.

NOTE 17
This gives a permitted tolerance for resistors, capacitors and inductors of ± 2 %.

The total uncertainty of measurement is, nevertheless, very important and each test laboratory use procedures which minimise uncertainty. Inter-laboratory comparisons, as encouraged in EN 45001, ISO/IEC Guide 25 and similar documents, should be employed to minimise the total differences in uncertainty of measurement between accredited laboratories. Where such inter-laboratory comparisons lead to standardised test methodologies, test techniques, or preferred test apparatus which are not detailed in the type-test standard, then this information shall be published in a timely manner. The information shall be in a form which is readily available to all laboratories, accredited and non-accredited, and shall additionally be forwarded to the committee responsible for producing the type-test standard, so that the standard may be improved accordingly.

NOTE 18
The term "accredited laboratory" refers to a laboratory which has been formally evaluated against an accepted quality system standard for laboratories (such as EN 45001) by a nationally recognised accreditation body (such as NAMAS in the UK). A "non-accredited laboratory" has not been accredited in this way (but may have an equal level of competence).

8.3 Uncertainty as applied to conditions of test

8.3.1 General

Requirements in this clause describe how uncertainty of metering and gauging is to be taken into account when setting up the conditions of test defined within a type-test standard.

It is not possible to set and maintain a single set point throughout an entire test since, in practice, the "point" will fall within a range due to factors such as:

- measurement uncertainty for the meters and gauges used to set and monitor the applied quantity;
- the equipment used to apply the set conditions may only permit setting in discrete steps, with no step available at the exact set value;
- the applied conditions drift with time, ambient temperature, etc.

The considerations described above may also be found where a set range is specified.

The following general terms are used:

$+ U_t^p$	upper limit of uncertainty for metering and gauging, as permitted in annex A;
$- U_t^p$	lower limit of uncertainty for metering and gauging, as permitted in annex A;
$+ U_t^a$	upper limit of total (or combined) uncertainty of metering and gauging for the actual meter(s)/gauge(s) used;
$- U_t^a$	lower limit of total (or combined) uncertainty of metering and gauging for the actual meter(s)/gauge(s) used.

NOTE 19
Where a single meter or gauge is used, (±) U_t^a is calculated as per (±) U_{ts} in 7.3. Where a combination of meters or gauges are used, (±) U_t^a is calculated as per (±) U_{tc} in 7.4.

Set conditions need to be maintained throughout the duration of the test, within the uncertainty specified. The difference between Utp and Uta is the normally permitted allowance for drift in test conditions. In exceptional circumstances it may not be possible to maintain set conditions to this degree of accuracy, due to limitations of the best available test equipment at that laboratory. Where this is the case, the conditions shall be adjusted to be as close as possible to those required in the type-test standard.

NOTE 20
Where it is not possible to maintain the set conditions within the range required by this standard it is usual to adjust the test to be more severe than that required by the type-test standard. This may not be possible in all cases, for example, it may not be possible to maintain all parts of a physically large machine within the limits of 8.3 over a set environmental range.

The range of conditions actually applied shall be recorded in the test report. Whenever the required set conditions have not been maintained within the required limits, this shall be clearly and visibly stated in the test report.

8.3.2 Set point

The set point, specified by the type-test standard is Sp.

For this example it is assumed here that $+U_t^p$, $-U_t^p$, $+U_t^a$, $- U_t^a$, are all symmetrical about Sp.

The range of set conditions permitted when performing the test, Sc, is given by:

$$(\pm)Sc = Sp \pm (|U_t^p| - |U_t^a|)$$

NOTE 21
As explained in 8.3.1, the extent to which applied set conditions are permitted to deviate from the set point depends upon the measuring instruments/gauges used.

This is shown diagramatically in figure 1.

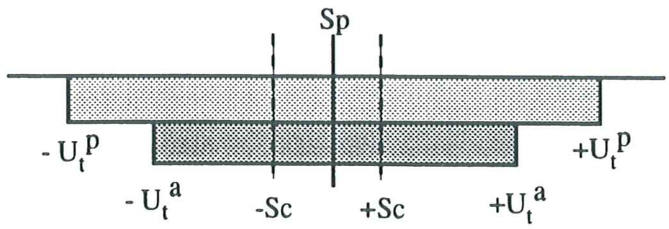


Figure 1

NOTE 22
The following example can be considered:
When performing a temperature rise test in accordance with ECMA-129 it is necessary to set the ac input voltage to 240 V + 6 % = 254,4 V.
From annex A, U_t^p *= ± 1,5 % {= ± 3,8 V (for 254,4 V)}.*
Therefore the actual input voltage is to be maintained within a band from 250,6V to 258,2V for the duration of the test (= $-U_t^p$ *to* U_t^p*).*
If the actual voltmeters used have an uncertainty, U_t^a *= ± 8 % {= ± 2 V (for 254,4 V)} then Sc = (3,8 - 2) V = ± 8 V and the meter reading must be maintained within the range 252,6 V to 256,2 V.*

8.3.3 Set range

The set range specified in the type-test standard has upper and lower limits of Sr^+ and Sr^- respectively.

For this example it is assumed here that $+U_t^P$, $-U_t^P$, $+U_t^a$, $-U_t^a$ are all symmetrical about the point midway between SR^- and SR^+ respectively.

The set conditions are permitted to be within a range from

$$-Sc^- = (Sr^-) - (|U_t^P| - |U_t^P|)$$

to

$$+Sc^+ = (Sr^+) - (|U_t^P| - |U_t^a|)$$

This is shown diagramatically in figure 2.

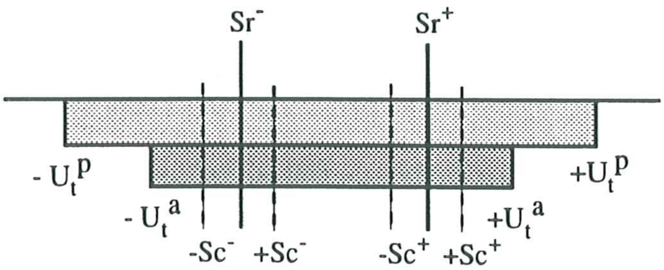


Figure 2

NOTE 23
The following example can be considered:
A humidity conditioning test requires the equipment to be contained within an environment of 93 % R.H. ± 2 % R.H. = 91 % R.H. to 95 % R.H. {= Sr^- *to* Sr^+*}*
From annex A, U_t^p *= ± 5 %*
Therefore the humidity is to be maintained within a band from 86 % R.H. to 100 % R.H. (in practice, however, a value of less than 100 % R.H. will be required to prevent condensation).
If the actual humidity meter used has an uncertainty U_t^a *= ± 4 % R.H., then Sc = ± 1 % and the meter reading must be maintained within 90 % to 96 % R.H.*
In this example it would be permissible to use a meter having an uncertainty U_t^a *= ±6 %, (i.e. greater than that provided in annex A) in which case the meter reading must be maintained within 92 % R.H. to 94 % R.H.*

8.3.4 Set maximum/minimum

The set maximum value, specified by the type test standard, is S_{max}.

The set minimum value, specified by the type test standard, is S_{min}.

The set nominal values, required by the condition of test due to meter(s) or gauge(s) used are Sn_{max} and Sn_{min} for S_{max} and S_{min} respectively.

For this example it is assumed that $+U_t^p$, $-U_t^p$, $+U_t^a$, $-U_t^a$ are all symmetrical about Sn.

The range of set conditions permitted when performing the test is given by:

Upper value $|S_{max}| > |+U_t^a|$; lower value $|S_{max}| \leq |-U_t^a|$

Upper value $|S_{min}| \leq |-U_t^a|$; lower value $|S_{min}| \geq |-U_t^a|$

This is shown diagramatically in figure 3.

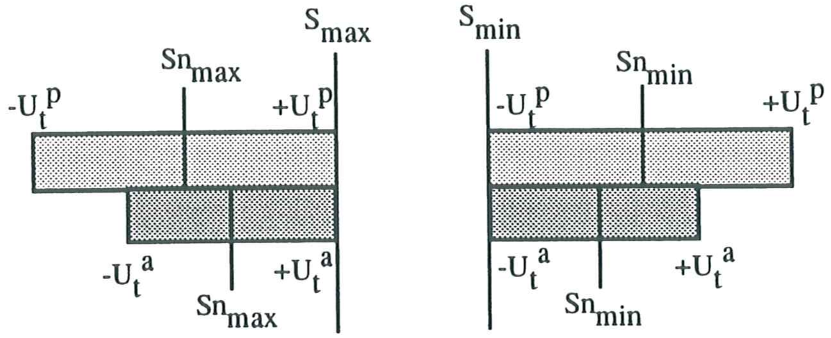


Figure 3

NOTE 24
The following example can be considered:
A test requires equipment to be cycled between two temperatures.
*At the 'low' limit the sample must be at a temperature of **no more than** 10°C {$=S_{max}$}*
*At the 'high' limit the sample must be at a temperature of **not less than** 10°C {$=S_{min}$}*
From annex A, $U_t^p \pm$ 2°C
Therefore the temperature set points are Sn_{max} = 8°C and Sn_{min} = 82°C.

The sample may actually see a temperature range of 6°C to 84°C {$=S_{max} - 2|U_t^p|, S_{min}, + 2|U_t^p|$}.

If the actual measuring instrument used has an uncertainty , $U_t^a = \pm$ 0,5°C, and the temperature set points are Sn_{max} = 9,5°C and Sn_{min} = 80,5°C, the sample is then actually maintained within a temperature range of 9°C to 81°C (providing this is within the control accuracy of the chamber).

8.4 Uncertainty as applied to limit values

8.4.1 General

The following requirements relate to how uncertainty of metering and gauging is to be applied when considering how test results compare with limit values defined within type-test standards. Terms $+U_t^p$, $-U_t^p$, $+U_t^a$, $-U_t^a$ have the same meaning as in 8.3.1, and the following additional general terms are also used:

- V^u upper limit value;
- V_l lower limit value;
- M_r measured result;

The limit values, V^u and V_l, are as defined in the type-test standard and may form the upper and lower limits of a band. The measured result, M_r, is assumed to be symmetrically centred between $+U_t^a$ and $-U_t^a$. All values are treated as being absolute.

8.4.2 Reporting compliance

The following terms and criteria, shown diagramatically in figure 4, shall be used when reporting the results of a type test:

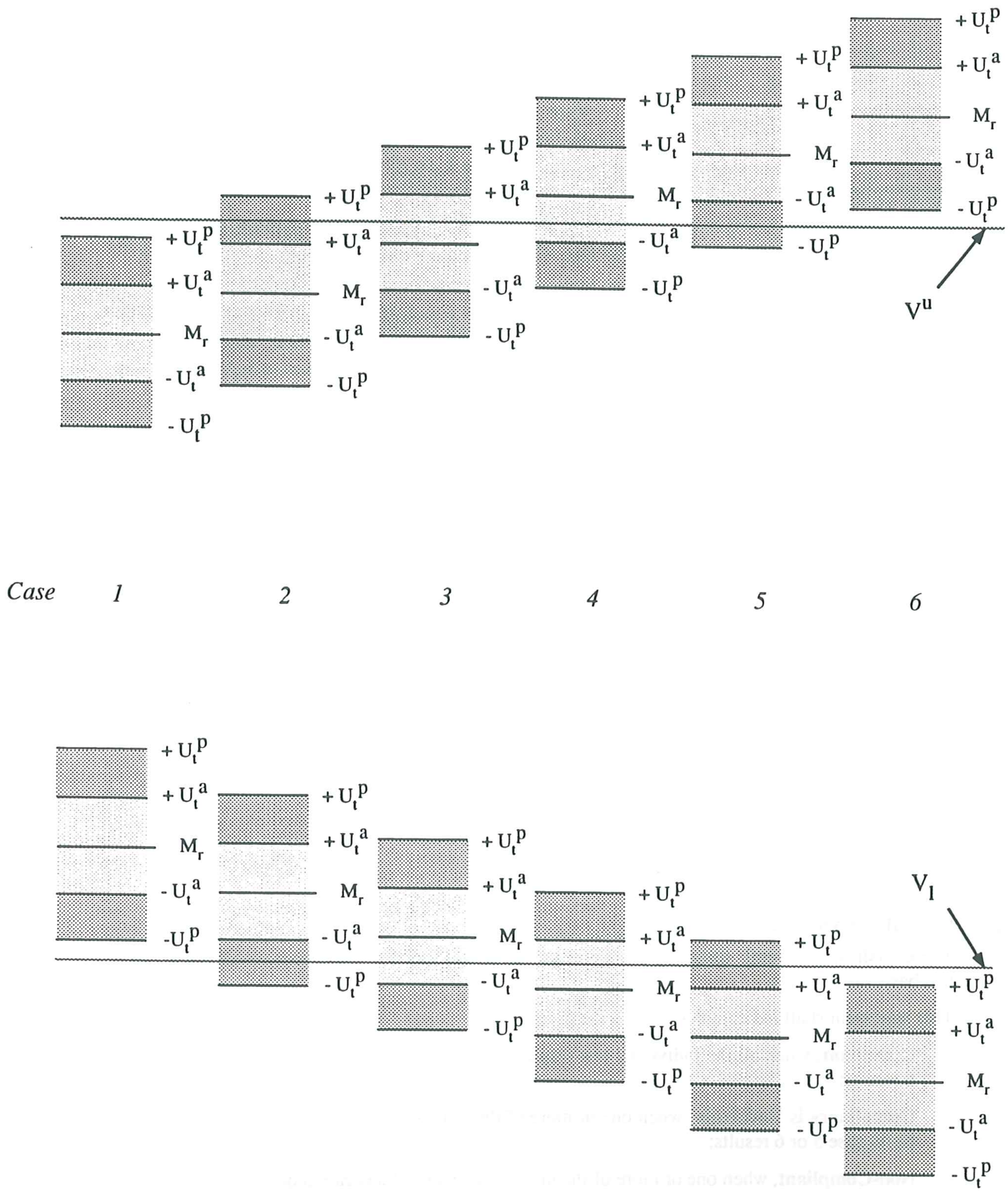


Figure 4

Case	Upper limit	Lower limit	Reported result
1	$V^u \geq + U_t^p$	$V_l \leq - U_t^p$	Compliant
2	$+ U_t^p > V^u \geq + U_t^a$	$- U_t^p < V^u \leq - U_t^a$	
3	$+ U_t^a > V^u \geq M_r$	$- U_t^a < V^u \leq M_r$	Compliance
4	$M_r > V^u \geq - U_t^a$	$M_r < V^u \leq + U_t^a$	uncertain
5	$- U_t^a > V^u \geq - U_t^p$	$+ U_t^a < V^u \leq + U_t^p$	
6	$- U_t^p > V^u$	$+ U_t^p < V^u$	Non-compliant

NOTE 25

The responsibility of test laboratories is to report the results as found, not to state whether certification should, or should not, be granted. Refer to 9.2 for this. (This note is under revision)

NOTE 26

Depending on the capability of the laboratory, U_t^a can approach U_t^p. Hence a laboratory with equipment having a small degree of uncertainty would report a case 2 result as 'compliant', whereas another laboratory having equipment with a larger degree of uncertainty (approaching, or equal to U_t^p) would report the same measured value as 'compliance uncertain'.

8.5 Reporting of uncertainty

8.5.1 Individual test results

Reports containing type test results shall contain the following information regarding uncertainty of metering and gauging:

- details of measured quantity in connection with a set point or set range;
- a clear indication where the uncertainty of metering and gauging, in relation to the Set Point/Set Range, extends beyond that permitted in annex A (see 8.2);
- the measured value of a parameter used to determine compliance, together with the associated uncertainty value, where appropriate;
- a compliant/compliance uncertain/non-compliant statement, together with the case number as defined in 8.4.2.

Where the result of a particular test corresponds to case numbers:

1 or 6 — then only the measured value need be given in the test report; it is not required to give both the measured value and the associated uncertainty;

2, 3, 4 or 5 — then both the result and the associated uncertainty shall be given; this shall be in the form x ± U_t, where "x" is the measured value and "U_t" is the total systematic uncertainty for the measuring/gauging instrument used (see 7.3).

8.5.2 Overall summary statement

There shall be an overall summary statement in addition to individual compliance statements made on a per-test basis (as in 8.5.1).

This statement shall indicate that overall the product is:

- **Compliant**, when all the individual test results are either case 1 or case 2; there shall be no case 3, 4, 5 or 6 results;
- **Compliance is Uncertain**, when one or more of the individual test results are case 3 or case 4; there shall be no case 5 or 6 results;
- **Non-Compliant**, when one or more of the individual test results is case 5 or case 6.

Where the overall result is "Compliance is Uncertain", or "Non-Compliant", the individual results which led to that overall statement shall be identified.

Only systematic uncertainty for metering and gauging has been considered, which is considered for a confidence probability of not less than 95 %.

9 Requirements relating to certification

9.1 General

The requirements in this section pertain to organisations who perform product certification. Hence, the requirements apply to both:

- suppliers, who issue a declaration of conformity, and
- approval agencies, who issue a type approval certificate.

Product certification relies on the results of type tests performed by test laboratories, usually in conjunction with appropriate ongoing surveillance of the manufactured type. It is therefore the responsibility of the certification body to assure itself that each product manufactured will meet a set of minimum requirements; this does not, however, imply that each and every unit produced will comply with the type-test standard.

If the limits are exceeded by not more than the systematic uncertainty of measurement, the equipment under test should not be rejected if standards are applied in which the uncertainty of measurement is not explicitly mentioned and taken into account in the limits.

9.2 Certification statements

Product certification shall be related to type test results as follows, where case numbers and test results are defined in 8.4.1.

Case	Test results reported	Certification granted?
1	Compliant	Yes
2	Compliant	Yes
3	Compliance uncertain	Yes
4	Compliance uncertain	No
5	Non-compliant	No
6	Non-compliant	No

NOTE 27
In exceptional circumstances a certification body may grant product certification to a product in cases 4 and 5. In such a case, the reason shall be stated on the certificate. In case 4, the last paragraph of 9.1 shall be taken into account.

NOTE 28
Such a situation could occur when a type-test standard is known not to have taken uncertainty of measurement into account. In this case it may be necessary for all certification bodies to adjust the criteria for granting certification approval until such time as the type test standard is updated.

Annex A

(Normative)

Maximum limits of uncertainty for metering and gauging

A.1 General

Notes

- *Other parameters and ranges are under consideration.*
- *Where a parameter is described as being "up to x", this should be taken to refer to "up to and including x". Similarly, a range x - y includes both x and y, unless otherwise stated.*
- *The following table gives figures which quality instrumentation can achieve and is provided for guidance. The measurer should determine his maximum uncertainty consideration and make his selection accordingly.*

A.2 Electrical quantities

Quantity (Steady State) Direct Instrumentation	Permissible limit, value of U_t
dc	
Voltage below 1 V	± 0,5 % ± 0,1 mV
Voltage 1 V to 1000 V	± 0,5 %
Voltage above 1000 V	± 2,5 %
Current below 2 A	± 0,5 %
Current 2 A to 20 A	± 1,5 %
Current above 20 A	± 2,5 %
ac RMS and ac + dc RMS - 40 Hz to 1000 Hz	
Voltage below 1 V	± 1,5 % ± 0,1 mV
Voltage 1 V to 1000 V	± 1,5 %
Voltage above 1000 V	± 5 %
Current below 2 A	± 1,5 %
Current 2 A to 20 A	± 2,5 %
Current above 20 A	± 3,5 %
Leakage current < 30 mA ac RMS 50 Hz to 60 Hz	± 3,5 %
Leakage current < 30 mA ac RMS 5 KHz	± 5 %
Power up to 1 W 40 Hz to 60 Hz	± 5 mW
Power above 1 W and up to 3 KW 40 Hz to 60 Hz	± 1,5 %
Power above 3 kW 40 Hz to 60 Hz	± 5 %
Resistance	
General circuit - 100 mΩ to 10 MΩ	± 1 %
General circuit - below 100 mΩ - above 10 MΩ	± 5 %
Earth continuity (at a stated test current)	± 10 %
Insulation (up to 10 MΩ at a nominal 500 V dc)	± 10 %
Capacitance 10 pF - 10 µF at 1 kHz	± 1 %
Inductance 10 nH - 10 H at 1 kHz	± 1 %

Where it is necessary to make an (RMS) measurement on waveforms that are substantially non-sinusoidal, the meter should be Root Mean Square (RMS) sensing with a minimum full scale crest factor capability of 3 for voltage and 2 for current, unless otherwise stated in the type-test standard. If the crest factor of the waveform exceeds the meter's capabilities, then either an oscilloscope should be used, in which case the permissible limit is ± 10 %, or a thermal sensing instrument may be used.

Waveforms which visually appear non-sinusoidal on an oscilloscope trace should be measured using a true RMS meter.

Where an ohmmeter is used to determine temperature rise by change of resistance method, then the permissible value of U_t = ± 0,5 %; it is recommended that 4-wire measurement be used below 500 Ω .

A.3 Non-electrical quantities

Quantity (Steady State) Direct Instrumentation	Permissible limit, value of U_t
Time and time interval up to 5 sec. Time and time interval above to 5 sec.	± 0,2 % ± 1 %
Mass up to 10 g Mass above 10 g and up to 100 g Mass above 100 g	± 0,5 % ± 1 % ± 2 %
Relative humidity, 30 % - 95 %	± 5 %
Force	± 2 %
Torque	± 10 %
Angles	
Functional dimension of a gauge, up to 16 ° Functional dimension of a gauge, above 16 ° Metered	± 1,5 % ± 15' (*) ± 1°
Linear dimensions up to 25 mm Linear dimensions above 25 mm	± 0,05 mm ± 0,25 mm
Temperature up to 100 °C	± 2 °C
Temperature above 100 °C and up to 500 °C	± 2%
Temperature over 500 °C	± 10 °C

Other parameters and ranges are under consideration.

(*) Note: This figure aligns with a current proposal within IEC TC74 to modify tolerances on the test finger.

Annex B

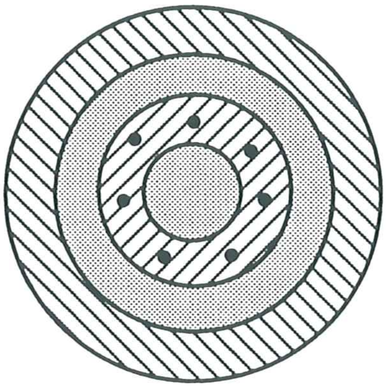
(Informative)

Introduction to some mathematical concepts regarding uncertainty

B.1 Error and Uncertainty

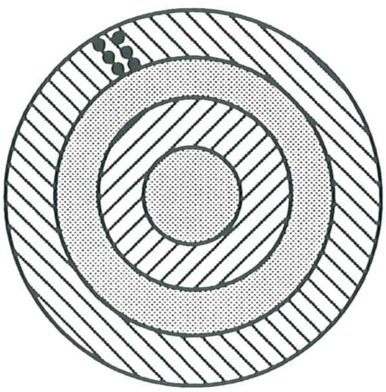
The error in a measuring system can be equated to the accuracy of the system whilst the uncertainty can be related to the consistency of the system. For example, in archery the desired outcome is to hit the bulls eye. The accuracy of your shooting is such that you hit the target consistently at 12 o'clock but with tight grouping, thus giving error with low uncertainty. The opposite may also occur where the error is small but uncertainty is high. In an ideal case small errors and uncertainties are preferred. These possible outcomes are illustrated in the diagrams below.

Small error
Large uncertainty



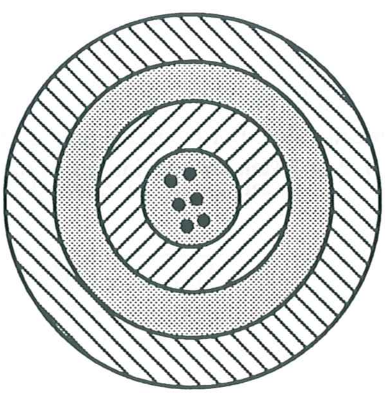
High accuracy/
Low consistency

Large error
Small uncertainty



Low accuracy/
High consistency

Small error
Small uncertainty



High accuracy/
High consistency

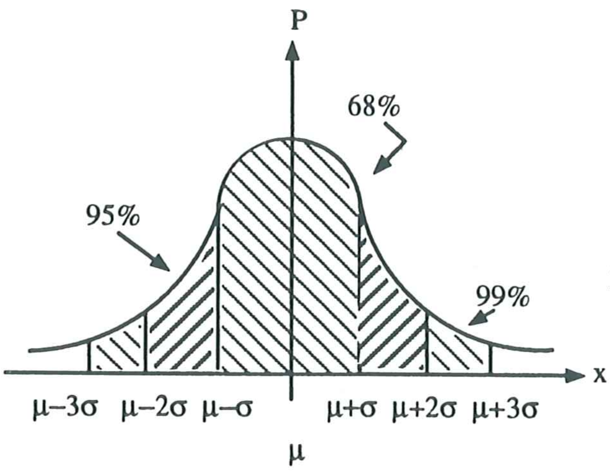
It will be seen that the preceding explanation requires consideration of a number of events.

Hence, central to the issue of the understanding of uncertainty is probability distribution.

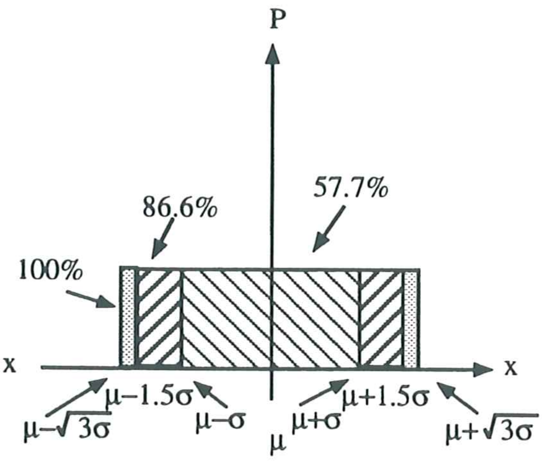
B.2 Probability

B.2.1 Population distributions

The probability distribution of a number of measurements of the same quantity is often of the form of a Gaussian (also called Normal) curve. Another form, the rectangular distribution, will also be discussed. In all cases, irrespective of the distribution, the area under the curve of the distribution is unity. The two distributions are depicted below.



Gaussian



Rectangular

The x-axis represents the range of possible measured values and the p-axis represents the probability of a corresponding x-value occurring.

The above curves show a population distribution where,

x measured value

n population size

μ population mean = $\frac{1}{n}\Sigma x$

σ Standard Deviation for the population mean, = $\sqrt{\frac{\Sigma(x-\mu)^2}{n}}$

In the Gaussian distribution most of the measured results occur around the mean value (μ), with no upper or lower bound to the values possible.

In the Rectangular distribution all possible measured values are equally likely, but a maximum and minimum value exists beyond which no values can exist.

The shape of each of these curves is defined by the value of the standard deviation (σ). This value quantifies the spread of measured results around the mean value. For Gaussian and Rectangular distributions the confidence of a measured result lying within 1, 1.5, 1.73, 2 or 3 standard deviations of the mean is given below:

Table B.1

Standard deviation	Gaussian	Rectangular
$\mu - \sigma < x \leq \mu + \sigma$	68 %	57,7 %
$\mu - 1,5\,\sigma < x \leq \mu + 1,5\,\sigma$	N/A	86,6 %
$\mu - 1,73\,\sigma < x \leq \mu + 1,73\,\sigma$	N/A	100 %
$\mu - 2\,\sigma < x \leq \mu + 2\,\sigma$	95,5 %	N/A
$\mu - 3\,\sigma < x \leq \mu + 3\,\sigma$	99,7	N/A

In general, the Rectangular distribution gives a higher confidence level for a value of uncertainty, and as a consequence, the rectangular distribution is assumed where no information is known about the distribution. The practical result of this is that, by assuming a Rectangular distribution, there is a higher confidence that the final uncertainty quoted will encapsulate all possible measurement values.

Measured results often obey a Gaussian distribution which consequently is the most commonly used.

It may be seen from the above that, for a Gaussian distribution, consideration of the 2 σ points give an area under the probability curves where 95 % of the results may be found. Translated into measurement we can say that the 2 σ points give approximately a 95 % confidence that a future reading ($\approx$ x) will lie within the limits of uncertainty (actually it is the 1.96 σ points).

B.2.2. Sample distributions

We have seen, in B.2.1, the two basic distribution curves which are applicable to uncertainty of measurement. However, the description so far has concentrated on the population distribution, where it is possible to determine quantities such as μ and σ directly by sampling all possible values of x. This approach does not lend itself to practical measurement, hence, only a defined number of measurements are made which constitute a sample of the whole population. Thus we have a sample mean ($\overline{x}$) and a sample standard deviation (σ_s). These are defined as below:

x_i= measured value

n = number of measurements made

$\overline{x}$ = sample mean

σ_{sg} = standard deviation for gaussian distribution

σ_{sr} = standard deviation for rectangular distribution

sample mean
$$\overline{x} = \frac{x_1 + x_2 + \ldots + x_n}{n}$$

This may alternately be written as:

$$\overline{x} = \frac{1}{n}\sum x_i \quad \{i = 1, 2, \ldots n\}$$

This definition of x is used for both the Gaussian and Rectangular distributions.

Standard deviation

For Gaussian distribution for small values of "n" we use:

$$\sigma_{sg} = \sqrt{\frac{\sum (x_i - \overline{x})^2}{n-1}}$$

NOTE
The (n-1) factor in the denominator gives a more accurate estimate of the standard deviation.

For Rectangularly distributed data is:

$$\sigma_{sr} = \sqrt{1/3\sum(x_i - \overline{x})^2}$$

Providing a sufficient number of measurements are made, it can be seen that $\mu \approx \overline{x}$ and $\sigma \approx \sigma_s$. It can also be shown that, for a sufficient number of sample points, the sample distribution may be treated as Gaussian, even if the population distribution is not Gaussian.

B.2.3 Confidence intervals

It will be seen that, by taking sample measurements, an estimate for μ may be determined. The extent to which $\overline{x}$ approximates to μ is a measure of the uncertainty. More precisely we can say that, by using the estimate of standard deviation, σ_{sg}, we can calculate limits about the sample mean ($\overline{x}$) that will embrace the population mean (μ) with a certain probability (U_r).

These confidence limits for the sample mean of a Gaussian distribution are:

$$x \pm U_r$$

where

$$U_r = t\left[\frac{\sigma_{sg}}{\sqrt{n}}\right]$$

t is the "students t factor" and varies with the required confidence level and the number of measurements in the sample. U_r is hence the random component of uncertainty.

The value of "t" for specified confidence limits as a function of "n" samples are as follows:

Table B.2

Sample size	Confidence limits				
n	50 %	68 %	95 %	99 %	99,7 %
5	0,74	1,14	2,78	4,60	6,62
10	0,70	1,06	2,26	3,25	4,09
15	0,69	1,04	2,14	2,98	3,64
20	0,68	1,03	2,09	2,86	3,45
∞	0,67	1,00	1,96	2,58	3,00

Each of these figures is multiplied by the sum of the uncertainties when expressed for one standard deviation.

Where we have a Rectangular distribution, the corresponding component of uncertainty (U_s) is given by

$$U_s = k\sqrt{\sigma_{s1}^2 + \sigma_{s2}^2 + \ldots + \sigma_{sm}^2}$$

where k = the value of "t" when $n = \infty$ (k must be greater than 1.8 for this equation to be valid).

$\sigma_{s1}, \sigma_{s2}, \ldots, \sigma_{sm}$ = standard deviations of individual semi-ranges.

If we wish to determine the total, combined, uncertainty (U) this may be found by RSS addition, i.e.

$$U = \sqrt{U_r^2 + U_s^2}$$

Annex C

(Informative)

Example calculations

C.1 Converting confidence limits to 95 %, for a single parameter

This standard requires all uncertainties to be stated with 95 % confidence limits. Not all data will necessarily be stated at these limits, and will consequently need to be converted. Where the data is, or may be assumed to be, Gaussian, then the equations and table given in B.2.3 are used to convert the uncertainty to 95 % confidence limits.

C.2 Addition of uncertainties where the confidence limits are not all stated at 95 %

To evaluate the combined uncertainty of a number of parameters, per 7.3, the confidence level of the data must be reduced to a common level before addition.

Thus, where the confidence limit is quoted at 95 % for one parameter and 68.3 % for a second, each is reduced to 68.3 % before addition is made and the weighting factor for each applied after the addition to obtain the required confidence level. This is true for both Gaussian and Rectangular distributions. The uncertainties are now added as an RSS addition.

In the event that the individual figures to be added have been originally derived from a mixture of rectangular and Gaussian data the RSS addition still applies since the standard deviation derived from the rectangularly distributed data has now been equated to a Gaussian value.

EXAMPLE
Consider the estimation of the uncertainty of an ESD discharge where:

- *the uncertainty of the scope probe is quoted as 5 % for*
- *the scope and the discharge target have values of 3.5 and 12 % respectively for a confidence limit of 95 %.*

In each case an infinite number of measurements is assumed.

Here is necessary to reduce each of the parameters to a common figure, in this case 68,3 %. Thus we have 3,5 and 12 % divided by 1,96 (see table B.1) giving figures of 1,53 and 6,12 respectively for 68,3 % confidence. If these are now summed using RSS addition we have a total uncertainty of:

$$\sigma(\text{Total}) = \sqrt{(1,53)^2 + (6,12)^2 + (5)^2}$$

= 8,05 % for a confidence limit of 68 %.

For 95 % confidence a multiplier of 1,96 will be applied, to give a figure of 15,78 %.