On the Uncertainty in the Immunity Standards of the IEC 61000-4-x Series

Ralf Heinrich

TESEQ GmbH, Landsberger Straße 255, 12623 Berlin, Germany
`ralf.heinrich@teseq.com`

***Abstract*— An overview on the handling of measurement uncertainty in the immunity standards of the IEC 61000-4-x series will be given in this paper. The first part discusses basic concepts of the uncertainty analysis and the calculation of an uncertainty budget. Later parts then apply these concepts to particular EMC immunity tests based on examples from the current status of work in the IEC standard committees.**

Key words: uncertainty, tolerance, calibration, distribution function, Type A, Type B, IEC 61000-4-x, immunity, ESD

I. INTRODUCTION

The proper operation of a device in its electromagnetic environment can be affected by different phenomena, e.g. ESD, Burst or other conducted or radiated interference. In order to ensure an interference-free operation of a device EMC immunity tests are carried out.

However, usually the immunity of a device under test cannot be tested directly in its intended electromagnetic environment. Therefore the EMC immunity tests are carried out according to well defined procedures and test conditions, which are defined in the immunity standards of the IEC 61000-4-x series as well as in the individual product standards. Each standard specifies the conditions for selected interference phenomena, like e.g. IEC 61000-4-2 [1] for ESD, IEC 61000-4-3 [2] for radiated disturbance etc.

The test result is affected by various factors and influences. These influences give rise to errors in the realization of the disturbance quantity. The conformance of the disturbance quantity realized by the test instrumentation with the disturbance quantity defined in the standard is usually confirmed by a series of measurements. The result of these measurements is only an approximation to the value of the measurand and the measured quantity may differ from the true value by some amount due to measurement uncertainty.

II. UNCERTAINTY ANALYSIS

For an uncertainty analysis it is necessary to identify the sources of uncertainty and how they can affect the test result. Generally the uncertainty sources can consist of unpredictable random effects and systematic effects.

Random effects affect the measurement value in a way that a series of measurements under constant conditions produces a scatter around a mean value as indicated in Fig. 1.

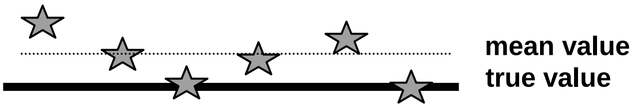

Fig. 1 Random errors around a mean

Random effects cannot be eliminated but deriving a mean value from an increasing the number of observations may reduce the uncertainty due to the random effects.

Examples for random effects are:

- environmental conditions
- noise on a DC voltage
- test set-up
- effects due to different operators

Systematic errors are reproducible and remain unchanged when a measurement is repeated under constant conditions. They produce an offset from the true value as indicated in Fig. 2.

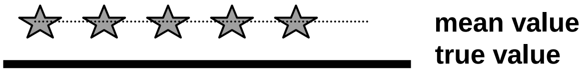

Fig. 2 Offset from true value due to systematic errors

Systematic errors can sometimes be corrected or reduced by applying a correction factor.

Examples for systematic effects are:

- wrong correction factor
- non-linearity of a measurement device
- harmonics of an amplifier

For uncertainty analysis the sources of uncertainty are grouped into one of two categories (Type A and B) based on their evaluation method. These normally correspond to the two types of effect described above.

Type A: those which are evaluated by statistical methods estimating their standard deviations for a population or sample of a population of test artifacts. This generally follows a Normal or Gaussian type of distribution

Type B: those which are evaluated by other means. They are usually associated with effects such as mismatch, cable losses, and instrumentation non-linearities. In an overall analysis the magnitude and distribution of Type B uncertainties can be estimated based upon calibration data, instrument manufacturer’s specifications or simply knowledge and experience.

III. COMPILATION OF AN UNCERTAINTY BUDGET

An uncertainty budget is a list of error sources and estimates individually their limits of uncertainty and probability function. In order to establish an uncertainty budget the possible error sources have to be identified. Furthermore their influence on the measurand has to be determined. The measurand is defined in the individual EMC standard as a specification of what is to be measured and usually a method for measuring it is defined as well.

However, the disturbance quantity may consist of several parameters (measurands), e.g. rise time and peak current value of an ESD pulse. Therefore more than one uncertainty budget may be necessary to fully characterize the uncertainty of the disturbance quantity.

The calculation of an uncertainty budget requires the following steps:

1. specification of the measurand (i.e. what is being measured)
2. identification of the contributions to uncertainty and their value
3. definition of the probability distribution of each contribution
4. calculation of the standard uncertainty $u(x_i)$ for each contribution
5. calculation of the combined uncertainty $u(y)$ and the expanded uncertainty U

1) The measurand can usually be derived from the disturbance quantity as it is defined in the standard.

2) The identification of the contributions to uncertainty requires a reasonable degree of familiarity with the test method and test instrumentation. All relevant influences should be listed. In some cases it may be useful to include a contribution with a low or zero value in order to acknowledge its presence in case it may turn out to have greater significance than at first thought.

The estimation of the value of an uncertainty contribution is done according to the methods mentioned in the previous section, Type A and B.

Type A can be used if a sufficient number of independent observations is available. In this case a statistical analysis can be applied. This method is often used for reproducibility investigations. Further information on Type A evaluation can be found in [3, 4, 5].

Type B evaluation is used if the uncertainty contribution is not evaluated by statistical means. This method gives more reliable data if the number of observations is small. Typical sources for Type B evaluation are for example data from calibration certificates, manufacturer’s specifications, previous measurements, data taken from literature, understanding of the instrument behavior and other relevant information or influence parameters.

3) Depending on the type of input quantity different probability distributions apply to Type B contributions. For EMC tests the relevant distribution functions are:

normal: for uncertainties derived from multiple contributions, e.g. calibration uncertainties or a statement of confidence

rectangular: equal probability of the true value lying anywhere between two limits, e.g. manufacturer’s specifications

U-shaped: applicable to mismatch uncertainty

triangular: should be assigned where the majority of the values between the limits lie around the central point

Type A contributions are already in the form of a standard uncertainty and need no further treatment.

4) The standard uncertainty $u(x_i)$ is calculated from the determined uncertainty of the input value x_i (e.g. value taken from the calibration certificate) by applying the divisor assigned to its probability contribution given in Table I.

TABLE I
DIVISORS FOR DISTRIBUTION FUNCTIONS

Distribution	Divisor
Normal	Coverage factor, *k*
Rectangular	√3
U-Shaped	√2
Triangular	√6

5) The combined uncertainty $u(y)$ for N contributions is calculated by the square root of the sum of squares of the individual standard uncertainties $u(x_i)$ (RSS method). This procedure is applicable provided that all input quantities are in the same units, are uncorrelated and combine by un-weighted addition in a logarithmic scale (usually dB). The input estimates x_i contribute to the output estimate y according to the model function:

$$y = f(x_1, x_2, \ldots, x_N) = \sum_{i=1}^{N} x_i \tag{1}$$

The contribution to the standard uncertainty associated with the output estimate y depends on the standard uncertainty associated with the input estimate x_i according:

$$u_i(y) = c_i u(x_i) \tag{2}$$

where the sensitivity coefficient c_i is given by the partial derivative of the model function with regard to the input quantity:

$$c_i = \frac{\partial f}{\partial x_i} \tag{3}$$

The combined uncertainty *u(y)* for N contributions is calculated by the square root of the sum of squares of the individual standard uncertainties $u(x_i)$.

$$u(y)=\sqrt{\sum_{i=1}^{N}u_i^2(y)} \tag{4}$$

By multiplying u*(y)* by a coverage factor *k* an expanded uncertainty, *U*, giving a greater confidence level can be achieved.

$$U=k\cdot u(y) \tag{5}$$

IV. APPLICATION EXAMPLES

A. *General*

The following uncertainty budgets are examples from the individual standards or drafts. The examples are intended to give guidance for the assessment of uncertainty. It should be noted that the disturbance quantity may consist of several parameters leading to several uncertainty budgets, although just one example is given here. Furthermore the list of uncertainty contributions may not be exhaustive, i.e. a lab may consider other contributions in addition. This especially applies to some Type A contributions. However, at least the contributions listed in the tables should be considered. The numbers given in the tables are examples only and should be replaced by the ones obtained from the individual uncertainty assessment in the lab. Further information especially regarding the explanation of the contributions can be found in the related documents.

B. *IEC 61000-4-2*

The edition 2.0 of the IEC 61000-4-2 [1] contains measurement uncertainty considerations in Annex E. An example for the rise time calibration is given in Table II.

TABLE II
ESD RISE TIME CALIBRATION

Contributor	**Distribution**	**Value ps**	**u_i (y) ps**	**$(u_i(y))^2$ ps^2**
Reading of peak value	k=2	50	25	625
Reading of time by 90 % peak current	rect.	25	14	196
Reading of time by 10 % peak current	rect.	25	14	196
Total oscilloscope horizontal meas. contribution	k=2	36	18	324
Target-attenuator-cable chain	k=2	30	15	225
Repeatability	k=1	45	45	2025
			Sum	3591
Combined standard uncertainty u(y)			Root	60 ps
Expanded uncertainty U on rise time	k=2	120 ps		

C. *IEC 61000-4-3*

The uncertainty for the IEC 61000-4-3 [6] is intended to be handled in a similar way as for the IEC 61000-4-6, i.e. establishing a budget for calibration and test. The major contributions for level setting in calibration can be found in Table III.

TABLE III
LEVEL SETTING CALIBRATION

Uncertainty Source X_i	**$U(x_i)$**	**Unit**	**Distribution**	**$u_i(y)$**	**Unit**	**$u_i(y)^2$**
Field probe calibration	1,7	dB	k=2	0,85	dB	0,72
Power meter	0,3	dB	rect.	0,17	dB	0,03
PA rapid gain variation	0,2	dB	rect.	0,12	dB	0,01
SW levelling precision	0,6	dB	rect.	0,35	dB	0,12
					$\Sigma u_i(y)^2$	0,88
					Combined uncertainty $u(y)=\sqrt{\Sigma u_i(y)^2}$	0,94
					Expanded uncertainty (CAL) U=u(y).k, k = 2	**1,88** **dB**

D. *IEC 61000-4-6*

The uncertainty is included in the edition 3 of the standard [7]. The IEC 61000-4-6 includes four different test methods. The uncertainty budgets for all test methods are divided into a budget for calibration and test. The Tables IV and V show the uncertainty budget for the conducted immunity using a CDN as an example.

TABLE IV
CDN CALIBRATION PROCESS

Uncertainty Source X_i	**$U(x_i)$**	**Unit**	**Distribution**	**$u_i(y)$**	**Unit**	**$u_i(y)^2$**
150 to 50 Ohm adapter, deviation	0,3	dB	rect.	0,17	dB	0,03
150 to 50 Ohm adapter, calib.	0,2	dB	k=2	0,10	dB	0,01
Set-up for level setting	0,35	dB	k=1	0,35	dB	0,12
Level meter	0,5	dB	rect.	0,29	dB	0,08
SW levelling precision	0,3	dB	rect.	0,17	dB	0,03
Level meter in control loop *1,2	0	dB	rect.	0,00	dB	0,00
Test generator *1,2	0	dB	rect.	0,00	dB	0,00
Mismatch Test generator/CDN	0	dB	U-shaped	0,00	dB	0,00
Mismatch Level meter/CDN	-0,5	dB	U-shaped	-0,35	dB	0,13
					$\Sigma u_i(y)^2$	0,40
					Combined uncertainty $u(y)=\sqrt{\Sigma u_i(y)^2}$	0,63
					Expanded uncertainty (CAL) U=u(y).k, k = 2	**1,27** **dB**

Some uncertainty sources (*1, 2) appear with zero contribution in the table depending on whether a level control for signal generator and amplifier output is used or not. The level meter for level control is used for calibration and test, therefore only the repeatability and linearity enter into the table for test. The mismatch from the test generator to the CDN can be neglected when the same circuit for calibration and test is used. The calibration uncertainty appears as one contribution in the test process uncertainty.

TABLE V
CDN TEST PROCESS

Uncertainty Source X_i	**$U(x_i)$**	**Unit**	**Distribution**	**$u_i(y)$**	**Unit**	**$u_i(y)^2$**
Calibration	1,27	dB	k=2	0,63	dB	0,40
Level meter in control loop *1,2	0,3	dB	rect.	0,17	dB	0,03
Test generator *1,2	0	dB	rect.	0,00	dB	0,00
Mismatch Test generator/CDN	0	dB	U-shaped	0,00	dB	0,00
SW levelling precision	0,3	dB	rect.	0,17	dB	0,03
					$\Sigma u_i(y)^2$	0,46
					Combined uncertainty $u(y)=\sqrt{\Sigma u_i(y)^2}$	0,68
					Expanded uncertainty U=u(y).k, k = 2	**1,36** **dB**

E. IEC 61000-4-22

Annex D of the current CD of the IEC 61000-4-22 [8] provides information about measurement uncertainties. Table VI shows the uncertainty budget for the measurement instrumentation uncertainty in the FAR for level setting in the frequency range 30 to 1000 MHz as an example.

TABLE VI
MEASUREMENT INSTRUMENTATION UNCERTAINTY IN THE FAR FOR LEVEL SETTING FOR IMMUNITY TESTING IN THE FREQUENCY RANGE 30 TO 1000 MHZ

Input quantity X_i	**Uncertainty of x_i**		**$u(x_i)$**	**c_i**	**$(u(x_i))^2$**
	dB	distribution	dB		dB
Instruments					
Power meter	0,7	rect.	0,40	1	0,16
Power amplifier gain variations	0,2	rect.	0,12	1	0,01
Software levelling window	0,6	rect.	0,35	1	0,12
Cable and Mismatch					
Cable attenuation	0,2	k=2	0,10	1	0,01
Mismatch TRP - receiver	0,9/ -1,2	U-shaped	0,74	1	0,55
System transducer factor					
Average system transducer	1,8	k=1	1,80	1	3,24
Field probe calibration	1,7	k=2	0,85	1	0,72
Frequency interpolation	0,3	rect.	0,17	1	0,03
Environment					
Separation distance of the antenna	0,3	rect.	0,17	1	0,03
			u(y)		2,21

V. APPLICATION

The calculated expanded uncertainty is intended to be used e.g. for laboratory accreditation or other purposes. However, it is not intended that the result of this calculation be used for adjusting the test level that is applied to EUTs during the test process.

If the measurement uncertainty is used to check compliance to tolerances as given in a standard, the compliance is deemed to be given if the corrected value (derived from the calibration results) is within the tolerance band, even if the expanded uncertainty may exceed the upper or lower limit of the tolerance band. This approach deviates from other concepts because the tolerances given in the standards of the IEC 61000-4-x series once were defined without taking uncertainties into account. More detailed explanations regarding this subject, especially on the handling of special cases can be found in [3].

VI. CONCLUSION

The immunity standards of the IEC 61000-4-x series contain or will contain informative annexes on measurement instrumentation uncertainty. The basic ideas and concepts for the handling of measurement uncertainty for immunity tests were presented and examples from current IEC working documents were given. The example budgets and lists of contributors shall help laboratories to establish their own uncertainty budgets. It is intended that at least these contributors should be used in order to achieve comparable uncertainty budgets.

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