EMC Measurement Uncertainty

a handy guide

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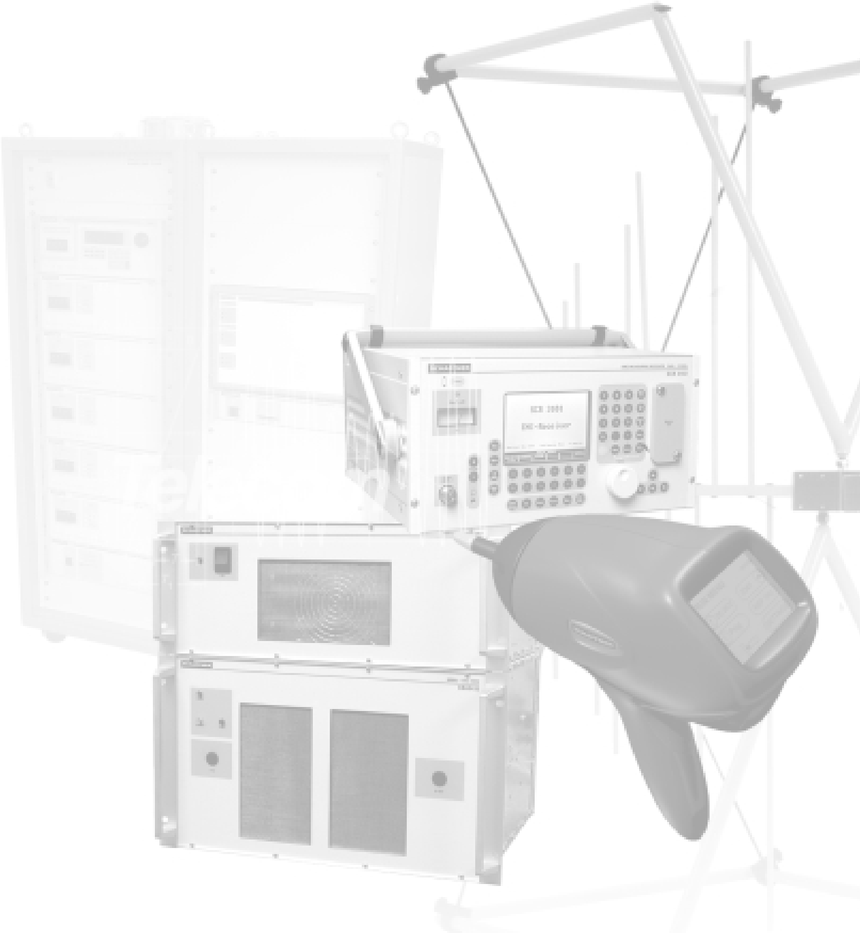


The Handy Guide to EMC Measurement Uncertainty

Introduction

EMC testing is a process of taking measurements. Whenever you measure a quantity, the result is never an exactly correct value: the value you report will inevitably differ from the true value by some amount, hopefully small. This applies whether you are measuring length, voltage, time or any other parameter, complex or simple. EMC measurements are no different in this respect. But the subject of measurement uncertainty in EMC tests is more complex than most because:

- the equipment that is being tested was not designed specifically for the test – there is no “EMC” connection port,
- the test method usually includes set-up factors that affect the measurement,
- the test equipment is itself complex and includes several separate but interconnected components,
- the quantities involved may be electromagnetic fields, varying in space, and may be transient or continuous.

Accredited test laboratories are required to know their uncertainty and to report it whenever this is relevant to the final result. But even if a laboratory is not accredited, it is helpful to go through the process of calculating an uncertainty budget. Once significant contributions have been identified, you can take steps to address and minimise them in the test procedure. Conversely, it may become evident that some contributions could be increased, through relaxations in equipment or procedures, without affecting the overall level.
A laboratory should also be aware whether or not its uncertainty is likely to affect the outcome of the test: if the result is close to the specification limit, it may not be possible to make a definitive statement of pass or failure.

This guide gives a clear and straightforward explanation of how measurement uncertainty is calculated and applied. The first part discusses the basic concepts of identification of the relevant contributions, and calculation of total uncertainty from these contributions. Later parts then apply these concepts to particular EMC tests. The guide follows the practice described in UKAS publication LAB 34, “The Expression of Uncertainty in EMC Testing” [1] (formerly published as NIS 81). That document is itself generally in line with the guidelines produced by the International Committee for Weights and Measures (CIPM), as described in the “Guide to the Expression of Uncertainty in Measurement” [2] (the GUM).

Basic concepts

EMC test standards include a specification of what is to be measured – the **"measurand"** – and define a method for measuring it. For instance, in the conducted emissions test, this is an RF voltage measured by a test receiver connected to the terminals of a LISN. The process of measurement is imperfect and errors creep into the result. As a consequence, the result of a measurement only ***approximates*** to the true value of the measurand and is only complete when it carries a statement of the **uncertainty** of that approximation. For any given measurement method, there are usually several sources of uncertainty, although only one or two may dominate. You need to analyse each individual source, assign a value to it, and then sum the values in an appropriate manner to give the total uncertainty. In general, a source of error may be either random or systematic; uncertainty arises directly from the random effects, and from the systematic effects when these are imperfectly corrected or not corrected.

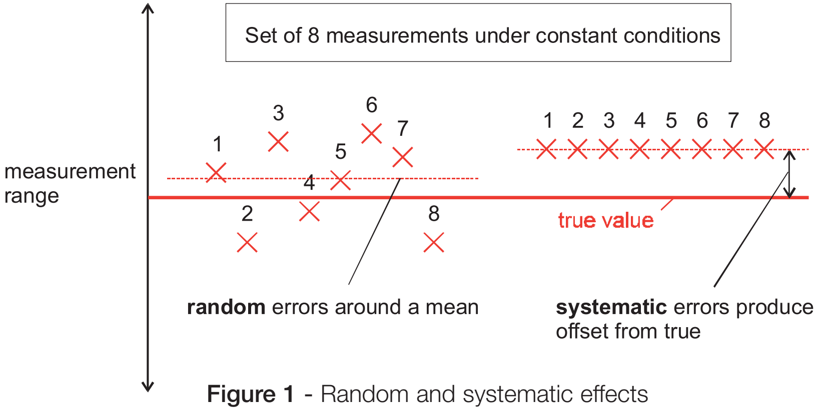


Figure 1 - Random and systematic effects

Whenever a measurement is taken under constant conditions, **random effects** – for instance, noise on a DC voltage – affect the measured value. A series of notionally identical measurements produces a scatter around a mean value. The random errors cannot be eliminated but increasing the number of observations and deriving a mean value may reduce the uncertainty due to their effect.

Systematic errors arise when a given quantity, which remains unchanged when a measurement is repeated under constant conditions, influences the result – such as a calibration error. A systematic error introduces an offset between the true value of the measurand and the mean measured value. It may be possible to reduce such effects by applying a correction factor to the data, if the expected error is constant and known. If this is not done, then the full error must be included in the uncertainty budget.

An **uncertainty budget** lists the likely error sources and estimates individually their limits of uncertainty and probability distribution. To establish this list you need a reasonable degree of familiarity with the test method and the test instrumentation. When creating the list, it is better to be inclusive rather than exclusive – if a particular contribution turns out to be negligible, it is still better to acknowledge its presence and include it at a low or zero value than to ignore a contribution that may turn out to have greater significance than at first thought. Once you have analysed each component, the individual components are summed to produce the final result for the measurement.
In the analysis, sources of uncertainty can be grouped into one of two categories based on their method of evaluation. These normally correspond to the two types of effect described above.

Type A contributions: random effects

'Type A' evaluation is done by calculation from a series of repeated observations, using statistical methods, and resulting in a probability distribution that is assumed to be normal. For any measurement method, you should make a type A evaluation on that procedure and configuration that is typically involved in the test, using if necessary a standardised EUT (for instance, in the emissions tests, a comparison noise emitter). This will give a measure of the likely contribution due to random fluctuations, for instance uncontrolled variations in antenna position, the test environment, or losses through cable re-connection.
In the general case, you will be testing many different types of EUT and it is rarely practical to perform many repeat measurements on each type (but see below). Therefore the Type A contribution that is analysed in this way does not include a contribution for random variations due to the EUT, but such variations from all other sources in the measurement set-up can be determined. On the other hand, if you will always be testing one type of EUT – for instance in the production control environment – then the repeated measurements can be done on this EUT and the evaluation then does include this source.

A pre-determination of the uncertainty due to random contributions is given by the standard deviation $s(q_k)$ of a series of n such measurements q_k :

$$s(q_k) = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}(q_k - Q)^2}$$

where Q is the mean value of the n measurements. This value of $s(q_k)$ is used directly for the uncertainty due to random contributions, excluding the effects of the EUT, when only one measurement is made on the EUT. But if the result of the measurement is close to the limit, it is advisable to perform several measurements on the EUT itself, at least at those frequencies that are critical. In this case, the uncertainty is reduced proportional to the square root of the number of measurements:

$$s(Q) = \frac{s(q_k)}{\sqrt{n}}$$

So that four repeat measurements on the EUT, taking the mean value, will halve the uncertainty due to random effects. Note that this has no effect on those other contributions, discussed below, which are analysed as Type B factors. If these dominate the uncertainty budget, then it is questionable whether making repeat measurements on the EUT, to reduce the random contribution, is worthwhile.

Type B contributions: systematic effects

'Type B' evaluation is done by means other than that used for 'Type A', for example, data from calibration certificates, previous measurements, manufacturers' specifications or an understanding of instrument behaviour, or other relevant information. It applies to systematic effects, that is those that remain constant during the measurement but which may change if the measurement conditions, method or equipment are altered. Equipment calibration, mismatch errors, and errors due to constant deviations in the physical set-up are examples of these effects.
If possible and practical, corrections for systematic effects should be applied.

A typical example of such a case would be where the measuring equipment calibration certificate gives a value for the correct reading for a given indication. You could then add this correction to the result so that only the uncertainty of the calibration itself would be left to account for. In practice, it is usually simpler to leave such errors uncorrected and use an overall (larger) value either from the manufacturer's specification – so that calibration is used merely to confirm consistency with this specification – or to take a maximum error from the calibration certificate, extended by the calibration uncertainty, and apply that.

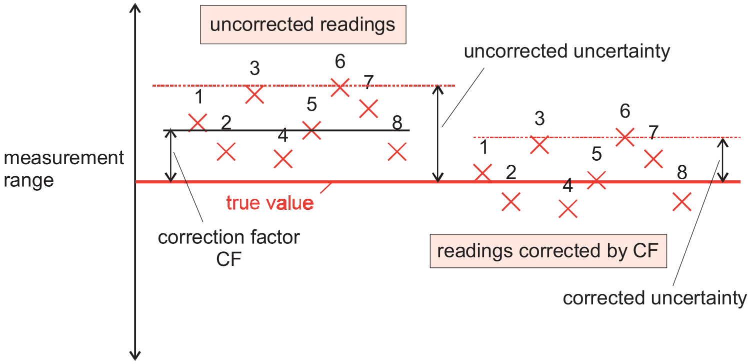


Figure 2 - Applying correction factors to reduce uncertainty

Other Type B contributions, not derived from calibration data or similar, have to be calculated from a knowledge of the nature of the test, often stated in simplified form. For instance, deviations in field strength due to errors in antenna separation are normally assumed to follow a 1/r law, and so you can calculate a contribution based on the degree of control exercised over the separation distance. Strictly, the 1/r assumption is not properly justified, but many such simplifications are necessary to keep uncertainty calculations in the realm of practicability.

Summation of contributions

Type A contributions are already in the form of a "standard uncertainty" and need no further treatment. Type B contributions need a further step before they can be summed. This involves determining the appropriate **probability distribution** for each contribution.

For EMC tests, the relevant probability distributions are;

- **normal:** uncertainties derived from multiple contributions, for example calibration uncertainties with a statement of confidence
- **rectangular**: equal probability of the true value lying anywhere between two limits, for example manufacturers' specifications
- **U-shaped:** applicable to mismatch uncertainty, where the probability of the true value being close to the measured value is low
- **triangular:** the probability of the true value lying at a point between two limits increases uniformly from zero at the extremities to the maximum at the centre; should be assigned where the majority of the values between the limits lie around the central point.

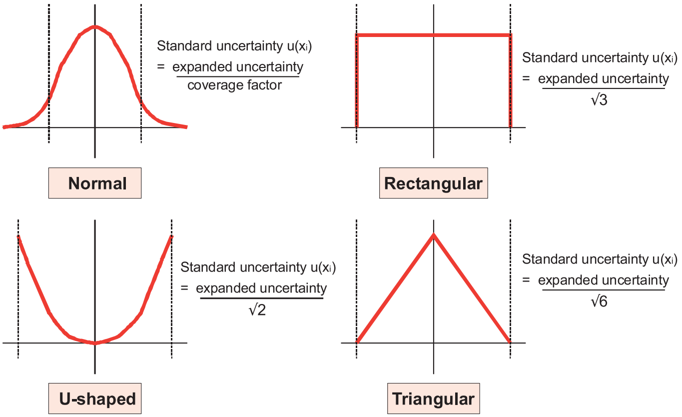


Figure 3 - Probability distributions

This describes the variation in probability of the true value lying at any particular difference from the measured result. Its actual form will often be unknown, and an assumption has to be made, based on prior knowledge or theory, that it approximates to one of the common forms. You can then calculate the **standard uncertainty**, $u(x_i)$, for the assigned form from simple expressions. The appropriate expressions are given in Figure 3 above.

If a particular uncertainty contribution is not in the same units as the required total uncertainty (such as, in the previous example, an uncertainty on distance creating a resulting uncertainty on field strength) then strictly speaking the contribution should be converted using a "sensitivity coefficient" c_i.

This then gives a series of "output" contributions $u_i(y)$. Practically, it is easier to leave the sensitivity coefficients at unity and quote all uncertainty contributions in the same units, so that summation becomes straightforward. A rigorous approach would in many cases need a non-linear sensitivity coefficient, for which the computational effort is rarely justified.

Once each contribution has been converted as above to a standard uncertainty, the **combined uncertainty**, $u_c(y)$, is obtained for ***m*** contributions by taking the square root of the sum of squares of the individual standard uncertainties:

$$u_c(y) = \sqrt{\sum_{i=1}^{m} u_i^2(y)}$$

Finally you have to calculate the **expanded uncertainty**, U. This defines an interval about the measured result that will include the true value with a specified level of confidence. The interval is greater than the standard uncertainty so that there is a higher probability that it encompasses the value of the measurand. The expanded uncertainty is obtained by multiplying the combined standard uncertainty by a **coverage factor**, k, which is set to 2 for a level of confidence of 95%. Other confidence levels can be obtained with different values of k, but the value of 95% is usual for industrial and commercial measurement applications.

Simplifications

Use of k = 2 to provide 95% confidence makes some assumptions about the probability distributions of the individual contributions. Also, the straightforward root-sum-of-squares approach to deriving the combined uncertainty assumes that the contributions are not correlated, that is, the input quantities are independent of each other. These assumptions are normally acceptable for EMC testing applications; LAB 34 discusses the issues further if you need to follow this up.

Some uncertainty contributions are asymmetrical: for instance the frequency step error or errors due to antenna directivity will tend only to reduce the reported result. Mismatch errors also have a slight asymmetry. It would be possible to calculate the entire budget twice, once for positive and once for negative contributions, and end up with an asymmetrical expanded uncertainty. But if the contributions are small in context, it is more practical simply to perform the analysis and include the larger contribution of the two as if it were bilateral (±) along with the other contributions.

Also, it can be argued that summing the squares of logarithmically quoted quantities (dB) is mathematically incorrect. Whether it is more appropriate to combine uncertainties in linear form or logarithmic form depends on whether their probability distributions are better described in linear or logarithmic form. The error introduced by combining all quantities in e.g. dB is usually marginal, and is offset by the greater clarity and simplicity of the result.

These simplifications are not the only ones; in the process of creating a budget you will discover many instances in which a much more rigorous treatment of an individual contribution is possible. In general, the effort needed to apply such a treatment is rarely justified by a significant improvement in the accuracy of the end result.

Applying the expanded uncertainty

The result of the measurement together with its expanded uncertainty can be reported in the following manner (for example):

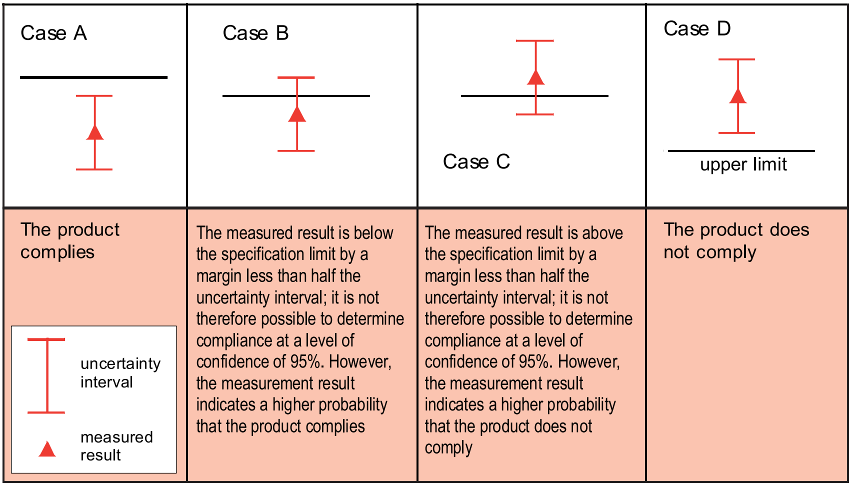
> *Measured value x dBμV*
>
> *Uncertainty of measurement ± y dB*
>
> *The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor of k=2, providing a level of confidence of approximately 95%.*

If particular known factors – such as the impact of EUT variations – have been excluded from the uncertainty calculation, then this should be stated in the above reporting format. If some uncertainty contributions vary over the complete range of the measurement, a single budget covering the complete range may mean that a larger uncertainty is assigned than is strictly necessary. It is entirely reasonable to split the measurement into sub-ranges and calculate and report a different uncertainty for each – for instance, the radiated emissions measurement may use different antennas for low and high frequencies, which have different error contributions, so the budget is split by frequency to reflect the ranges for each antenna (compare this with the approach taken on page 14). However, you may not want to do this in many cases where the calculation and reporting process should be kept simple.

Priority should be given to calculating the uncertainty in the region of the test specification limit, or limits. It is conventional to specify a radiated immunity field uncertainty at, for instance, 3V/m and 10Vm, which represent the majority of specification requirements.

The compliance statement

A test laboratory's customer normally wants to know whether his product has passed or failed the test. Ideally the specification would clearly state that the measured result, extended by the uncertainty at a given level of confidence, shall not fall outside a defined limit. Current EMC standards rarely do this.
The impact of measurement uncertainty is that, if the measured result is close to the compliance limit value by less than the expanded uncertainty, it is not possible to state compliance with a confidence of better than 95%. Either the laboratory should declare a result based on the example of Figure 4; or the client may decide to make a judgement of compliance himself, based on whether the result is within the specified limits with no account taken of the uncertainty. This is often referred to as 'shared risk', since the client takes some of the risk that the product may not have met the specification. In this case there is an implicit assumption that the magnitude of the uncertainty is acceptable, and therefore the laboratory has to be in a position to inform the client of its actual value. The difficulties presented by these problems have led to a number of proposed solutions within the international standards committees and their users. These are different as between emissions and immunity tests, and are discussed later in those sections.



Case A	Case B	Case C	Case D
The product complies	The measured result is below the specification limit by a margin less than half the uncertainty interval; it is not therefore possible to determine compliance at a level of confidence of 95%. However, the measurement result indicates a higher probability that the product complies	The measured result is above the specification limit by a margin less than half the uncertainty interval; it is not therefore possible to determine compliance at a level of confidence of 95%. However, the measurement result indicates a higher probability that the product does not comply	The product does not comply

Figure 4 - Possibilities for reporting compliance

Emissions uncertainties

This section gives examples of how to set up an uncertainty budget for each of the common EMC emissions measurements. The budgets are not intended to be used directly – each laboratory must calculate their own, based on knowledge of their particular systems and equipment. Even so, the figures given here are in line with typical practice.

They are as far as possible consistent with LAB 34 [1] and CISPR 16-4 [3], but there are differences between these two documents and the tables presented here do not follow either the values or the format exactly. The notes on the facing pages should illuminate any difficulties. For simplicity, application of the sensitivity coefficient c_i and the effect of revision of coverage factor k based on limited degrees of freedom of repeatability measurements (see annex B of LAB 34) have both been omitted from these tables.

As discussed earlier, repeatability of the EUT also is omitted from the tables.

Conducted tests

Conducted measurement 150kHz-30MHz, 50Ω 50µH LISN

	Contribution	Value		Prob. dist.	Divisor	$u_i(y)$	$u_i(y)^2$
1	Receiver reading	0.10	dB	Rectangular	1.732	0.058	0.003
2	LISN-receiver attenuation	0.10	dB	Normal	2.000	0.050	0.003
3	LISN voltage division factor	0.20	dB	Normal	2.000	0.100	0.010
4	Receiver sinewave accuracy	1.00	dB	Normal	2.000	0.500	0.250
5	Receiver pulse amplitude	1.50	dB	Rectangular	1.732	0.866	0.750
6	Receiver pulse repetition rate	1.50	dB	Rectangular	1.732	0.866	0.750
7	Noise floor proximity	0.00	dB	Rectangular	1.732	0.000	0.000
8	Frequency step error	0.25	dB	Rectangular	1.732	0.144	0.021
9	LISN impedance	2.70	dB	Triangular	2.449	1.102	1.215
10	Mismatch	-0.734	dB	U-shaped	1.414	-0.519	0.269
	Receiver VRC	0.09					
	LISN VRC	0.90					
11	Measurement system repeatability	0.50	dB	Normal (1)	1.000	0.500	0.250
						$u_c(y)$	$\Sigma u_i(y)^2$
						⇐	
12	Combined standard uncertainty		dB	Normal		1.876	3.521
	Expanded uncertainty		dB	Normal, k = 2.0		**3.75**	

To be entered	▨
Calculated	▨

This table follows the practice proposed in LAB 34 and the draft CISPR 16-4. Work reported in [4] identified various other possible contributory factors when using the LISN under some circumstances. Refer to that document for more detail.

For *discontinuous interference* to CISPR 14-1 there is no practical way of combining the errors in pulse duration measurement with the common errors already shown for continuous emissions. All that can be assumed is that the discontinuous interference analyser has been demonstrated, through calibration, to meet the appropriate requirements. A similar approach is also taken later when considering transient immunity tests. The uncertainty budget therefore will be the same as for standard conducted emissions.

Notes

1. Receiver reading: uncertainty determined by least significant digit fluctuation, assuming a single reading
2. LISN-receiver attenuation: uncertainty on cable, connector and limiter loss; may include a contribution due to interpolation from a frequency table
3. LISN voltage division factor: from the cal certificate; may include a contribution due to interpolation from a frequency table
4. Receiver accuracy: from manufacturer’s specification or cal certificate
5. Pulse amplitude response: as above, may be ignored if the EUT is known not to emit pulsed disturbances
6. Pulse repetition rate response: as above
7. Noise floor: not expected to approach the measurement limit
8. Frequency step error: if an automated receiver is stepped in half-bandwidth increments, this contribution depends on the shape of the receiver’s bandwidth filter
9. LISN impedance: assuming a 20% tolerance on both magnitude and phase, and assuming a worst case EUT source impedance, but taking a triangular distribution as the probability of all worst cases occurring together is low
10. Mismatch: the receiver VRC assumes a CISPR16-compliant receiver and 10dB input attenuator; the LISN VRC is a function of the EUT impedance which is in general unknown, but unlikely to reach unity; a worst-case figure of 0.9 is a matter of judgement. The connecting cable is assumed to be well matched
11. VRC stands for Voltage Reflection Coefficient and is related to VSWR (Voltage Standing Wave Ratio) by;

$$\mathrm{VRC} = \frac{VSWR - 1}{VSWR + 1}$$

12. System repeatability: this Type A contribution is derived from multiple investigative measurements using a representative set-up and EUT

Radiated tests

Radiated measurement 30MHz – 1GHz at 10m

	Contribution	Value		Prob. dist.	Divisor	$u_i(y)$	$u_i(y)^2$
1	Receiver reading	0.10	dB	Rectangular	1.732	0.058	0.003
2	Cable loss	0.10	dB	Normal	2.000	0.050	0.003
3	Receiver sinewave accuracy	1.00	dB	Normal	2.000	0.500	0.250
4	Receiver pulse amplitude	1.50	dB	Rectangular	1.732	0.866	0.750
5	Receiver pulse repetition rate	1.50	dB	Rectangular	1.732	0.866	0.750
6	Noise floor proximity	0.50	dB	Normal	2.000	0.250	0.063
7	Antenna factor calibration	2.00	dB	Normal	2.000	1.000	1.000
8	Antenna directivity	0.50	dB	Rectangular	1.732	0.289	0.083
9	Antenna factor height dependence	2.00	dB	Rectangular	1.732	1.155	1.333
10	Antenna phase centre variation	0.30	dB	Rectangular	1.732	0.173	0.030
11	Antenna factor freq interpolation	0.25	dB	Rectangular	1.732	0.144	0.021
12	Cross polarisation and balance	0.90	dB	Rectangular	1.732	0.520	0.270
13	Measurement distance variation	0.20	dB	Rectangular	1.732	0.115	0.013
14	Site imperfections	4.00	dB	Triangular	2.449	1.633	2.667
15	Frequency step error	0.00	dB	Rectangular	1.732	0.000	0.000
16	Mismatch	-2.734	dB	U-shaped	1.414	-1.933	3.736
	Receiver VRC	0.33					
	Antenna VRC	0.82					
17	Measurement system repeatability	1.00	dB	Normal (1)	1.000	1.000	1.000
						$u_c(y)$	$\Sigma u_i(y)^2$
						⇐	
18	Combined standard uncertainty		dB	Normal		3.460	11.972
	Expanded uncertainty		dB	Normal, k = 2.0		**6.92**	

To be entered	▨
Calculated	🟧

This table illustrates the pitfalls of taking too wide a view of the uncertainty budget: many contributions are over-estimated because they only apply to a particular part of the frequency range. If as is more usual separate budgets are calculated for biconical and log periodic antennas (or separate frequency ranges for a BiLog) and for horizontal and vertical polarisation, you can expect to obtain a noticeably lower result.

Notes

1. Receiver reading: uncertainty determined by least significant digit fluctuation
2. Cable loss: uncertainty on attenuation from antenna to receiver
3. Receiver accuracy: from manufacturer's specification or cal certificate
4. Pulse amplitude response: as above, may be ignored if the EUT is known not to emit pulsed disturbances
5. Pulse repetition rate response: as above
6. Noise floor: if this is within a few dB of the limit, the noise power adds to the signal power and causes a potentially significant error
7. Antenna calibration: taken from the calibration certificate
8. Antenna directivity: the antenna can be closely aligned on boresight horizontally, but not vertically for the whole height scan. Not significant for a horizontally polarised biconical, but a log periodic type will show a directive response especially at close distance and high elevation
9. AF height dependence: derived from practical experience, worst case is the biconical in horizontal polarisation
10. Phase centre variation: only relevant for the log periodic, for which the change in phase-centre location with frequency causes a deviation from the required separation, not allowed for in calibration
11. AF frequency interpolation: between entries in a frequency table
12. Cross polarisation and balance: derived from practical experience, worst case is the biconical in vertical polarisation (balance), log periodic (cross-polarisation)
13. Measurement distance: errors in determining the perimeter of the EUT, distance measurement, and antenna mast tilt; assuming 1/d field strength proportionality
14. Site imperfections: the difference between the theoretical and actual normalised site attenuation for the particular site. The CISPR specification allows a maximum of ±4dB; actual sites may be better than this, and because of the high uncertainty of the NSA method a site which meets this criterion is unlikely to cause measurement errors approaching 4dB, so a triangular distribution is assumed
15. Frequency step error: assuming manual tuning is used for the final reading, this contribution is zero
16. Mismatch: assumes a CISPR receiver VSWR of 2:1 (attenuation 0dB) and a biconical (worst case) VSWR of 10:1 – not strictly CISPR compliant, but typical
17. System repeatability: this Type A contribution is derived from multiple investigative measurements using a representative set-up and EUT

Disturbance power

Disturbance power measurement 30MHz – 300MHz with MDS-21 clamp

	Contribution	Value		Prob. dist.	Divisor	$u_i(y)$	$u_i(y)^2$
1	Receiver reading	0.10	dB	Rectangular	1.732	0.058	0.003
2	Cable loss	0.10	dB	Normal	2.000	0.050	0.003
3	Receiver sinewave accuracy	1.00	dB	Normal	2.000	0.500	0.250
4	Receiver pulse amplitude	1.50	dB	Rectangular	1.732	0.866	0.750
5	Receiver pulse repetition rate	1.50	dB	Rectangular	1.732	0.866	0.750
6	Noise floor proximity	0.00	dB	Normal	2.000	0.000	0.000
7	Absorbing clamp calibration	2.50	dB	Normal	2.000	1.250	1.563
8	Cal factor frequency interpolation	0.20	dB	Rectangular	1.732	0.115	0.013
9	Effect of ambient disturbances	0.20	dB	Rectangular	1.732	0.115	0.013
10	Effect of environment	0.80	dB	Rectangular	1.732	0.462	0.213
11	Frequency step error	0.25	dB	Rectangular	1.732	0.144	0.021
12	Mismatch	-2.319	dB	U-shaped	1.414	-1.640	2.688
	Receiver VRC	0.33					
	Absorbing clamp VRC	0.71					
13	Measurement system repeatability	0.50	dB	Normal (1)	1.000	0.500	0.250
						$u_c(y)$	$\Sigma u_i(y)^2$
						⇐	
14	Combined standard uncertainty		dB	Normal		2.553	6.518
	Expanded uncertainty		dB	Normal, k = 2.0		**5.11**	

To be entered	▨
Calculated	🟧

This table follows the practice proposed in LAB 34 and the draft CISPR 16-4. Work reported in [4] identified various other possible contributory factors when using the clamp in either a screened or unscreened environment. Refer to that document for more detail.

Notes

1. Receiver reading: uncertainty determined by least significant digit fluctuation
2. Cable loss: uncertainty on attenuation from absorbing clamp to receiver
3. Receiver accuracy: from manufacturer's specification or cal certificate
4. Pulse amplitude response: as above, may be ignored if the EUT is known not to emit pulsed disturbances
5. Pulse repetition rate response: as above
6. Noise floor: not expected to be significantly close to the limit for this measurement
7. Absorbing clamp calibration: taken from the calibration certificate
8. Calibration frequency interpolation: between entries in a frequency table
9. Effect of ambient disturbances: mains disturbances which are inadequately isolated from the absorbing clamp can affect the result; it is normal to use a second clamp at the far end of the cable under test to suppress these ambient signals
10. Effect of environment: there is a difference between the environment in which the absorbing clamp is calibrated and that in which it is used; this contribution is based on an assessment of that difference when measurement is made on a common EUT in different environments
11. Frequency step error: if an automated receiver is stepped in half-bandwidth increments, this contribution depends on the shape of the receiver's bandwidth filter
12. Mismatch: assumes a CISPR receiver VSWR of 2:1 (attenuation 0dB) and an absorbing clamp VSWR of 6:1 – this can be improved and the associated uncertainty reduced by applying a 6dB attenuator on the output of the clamp, as proposed in [4].
    The cable between clamp and receiver is assumed to be well matched
13. System repeatability: this Type A contribution is derived from multiple investigative measurements using a representative set-up and EUT

The CISPR Uncertainty

The subject of measurement uncertainty and how it is to be applied for CISPR-based emissions standards has been under active discussion in CISPR/A for several years and the work has resulted in the publication of a new part of CISPR 16, CISPR 16-4 (3). The effect of this document is to specify,

- that measurement uncertainty U_{lab} must be calculated and quoted in the test report;
- what parameters must be included for the budgets for each of mains port conducted disturbances, disturbance power, and radiated electric field strength measurements;
- a table of uncertainty figures that are deemed to be representative for each of these tests (reproduced below);
- how to use these uncertainty figures.

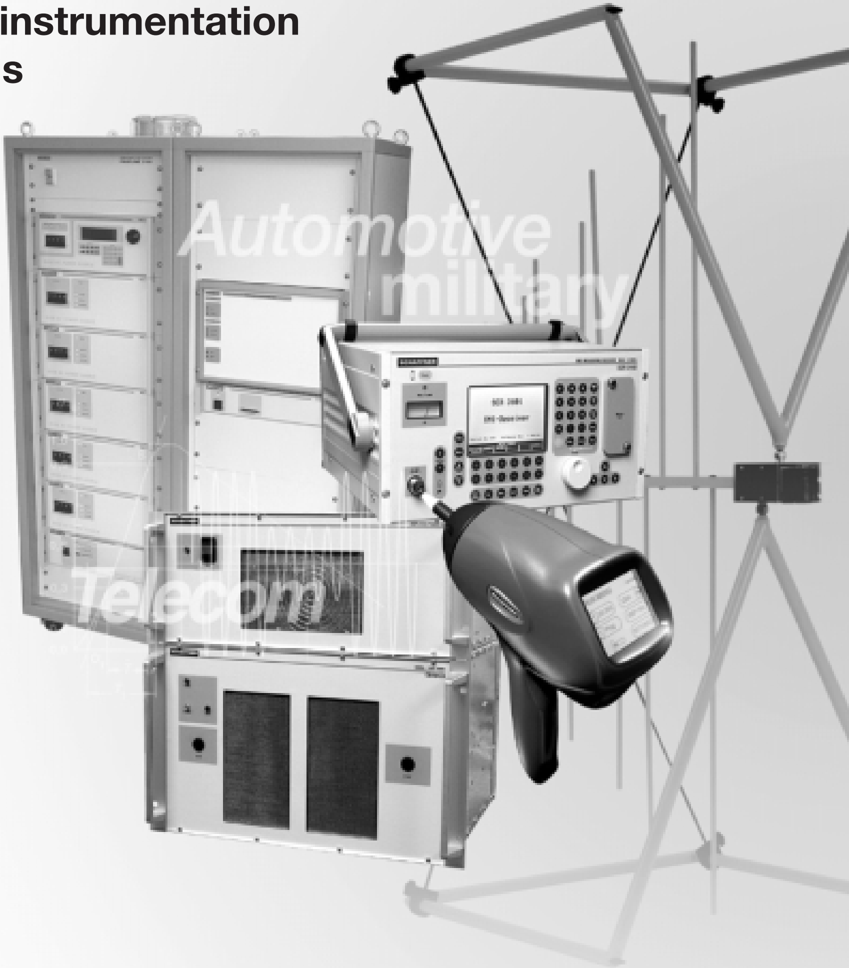
If the calculated uncertainty U_{lab} is <u>less</u> than that given for U_{CISPR} in the table, then

- compliance is deemed to occur if no measured disturbance exceeds the disturbance limit;
- non-compliance is deemed to occur if any measured disturbance exceeds the disturbance limit.

If the calculated uncertainty is <u>greater</u> than U_{CISPR}, then

- compliance is deemed to occur if no measured disturbance, increased by (U_{lab} – U_{CISPR}), exceeds the disturbance limit;
- non-compliance is deemed to occur if any measured disturbance, increased by (U_{lab} – U_{CISPR}), exceeds the disturbance limit.

Test method		**U_{CISPR}**
Conducted emissions	9kHz – 150kHz	**4.0dB**
	150kHz – 30MHz	**3.6dB**
Disturbance power	30MHz – 300MHz	**4.5dB**
Radiated electric field	30MHz – 1GHz	**5.2dB**


Automotive
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Immunity Uncertainties

This section gives examples of how to set up an uncertainty budget for each of the common EMC immunity tests. As with the emissions budgets, they are not intended to be used directly, but each user should calculate their own based on in-house procedures and equipment. Any contribution due to the non-repeatability of the EUT is omitted.

Radiated RF immunity

Radiated immunity measurement, 80MHz – 1GHz in anechoic chamber

	Contribution	Value		Prob. dist.	Divisor	$u_i(y)$	$u_i(y)^2$
1	Field strength monitor	1.20	dB	Normal	2.000	0.600	0.360
2	Field strength setting window	0.50	dB	Rectangular	1.732	0.289	0.083
3	Forward power measurement	0.20	dB	Rectangular	1.732	0.115	0.013
4	Amplifier harmonics	0.40	dB	Rectangular	1.732	0.231	0.053
5	Antenna-EUT coupling	0.30	dB	Rectangular	1.732	0.173	0.030
6	Effect of field disturbance	1.00	dB	Rectangular	1.732	0.577	0.333
7	Measurement system repeatability	0.50	dB	Normal (1)	1.000	0.500	0.250
						$u_c(y)$	$\Sigma u_i(y)^2$
						⇐	
8	Combined standard uncertainty		dB	Normal		1.060	1.123
	Expanded uncertainty		dB	Normal, k =	1.64	**1.74**	

To be entered	▨
Calculated	🟧

Test level multiplier for 95% confidence		Antilog(1.74dB/20)		1.222	
Revised test level	For:	3	V/m	3.66	V/m
		10	V/m	12.22	V/m

This table applies to tests done in accordance with IEC 61000-4-3 in a fully anechoic chamber. The field strength is calibrated over a uniform area and then the same forward power is re-played in the presence of the EUT, one face at a time aligned with the uniform area. The budget assumes that the 0–6 dB field uniformity requirement has been achieved.

There is disagreement as to how the resulting uncertainty value should be used, i.e. whether or not it should be added to the applied stress value.

If it is not added in, so that, say, the stress level is set to 3V/m, then the implication is that there is no more than a 50% confidence that the specification stress level has been applied.

If it is added (stress set to 3.66V/m in the above example) then there is 95% confidence that the EUT has been tested to at least the specification level.
In order to achieve a 95% confidence level, the expanded uncertainty must be calculated with a coverage factor k = 1.64. Assuming the distribution within the interval is normal, this sets the uncertainty interval to a 90% confidence level, which will then result in a 95% confidence of application of at least the correct stress. This approach is outlined in LAB 34 as a default to be taken unless the specification or an agreement with the client states otherwise.

Notes

1. Field strength monitor: this will be the uncertainty of calibration as reported on the field probe calibration certificate
2. Field strength setting window: the test software will have a preset window around the calibration field strength value within which the applied level is acceptable. A larger window allows faster settling between frequency steps but increases the uncertainty.
3. Forward power measurement: drift or other error attributable to the power meter and directional coupler used to monitor forward power, as between the calibration and the test
4. Amplifier harmonics: a contribution from the inclusion in the field strength measurement of harmonics due to amplifier non-linearity; this will increase as the amplifier approaches its maximum power and should be drawn from an investigation of the harmonic content into a representative load antenna at the power levels used for testing
5. Antenna-EUT coupling: the antenna VSWR will be modified by the presence of the EUT and this will cause a variation in the delivered field strength for a given forward power. This effect is greater at closer antenna-EUT distances and for larger EUTs
6. Effect of field disturbance: extraneous objects in the chamber that were not present during calibration, such as the supporting table and monitoring cameras, will disturb the field uniformity; the effect can be eliminated by including them (in fixed positions) during calibration, or by investigating their impact and including it here
7. Measurement system repeatability: this Type A contribution is derived from multiple investigative measurements using a representative set-up in the chamber, without an EUT

Conducted RF immunity (CDN)

Conducted immunity measurement 150kHz – 80MHz using CDN

	Contribution	Value		Prob. dist.	Divisor	$u_i(y)$	$u_i(y)^2$
1	Voltage level monitor	0.40	dB	Normal	2.000	0.200	0.040
2	50-to-150 ohm adaptor	0.10	dB	Rectangular	1.732	0.058	0.003
3	Voltage level setting window	0.50	dB	Rectangular	1.732	0.289	0.083
4	Signal source drift	0.20	dB	Rectangular	1.732	0.115	0.013
5	Amplifier harmonics	0.50	dB	Rectangular	1.732	0.289	0.083
6	Effect of layout variations	0.80	dB	Rectangular	1.732	0.462	0.213
7	Mismatch: CDN to voltage monitor	-1.230	dB	U-shaped	1.414	-0.869	0.756
	Voltmeter VRC	0.20					
	CDN + adaptor VRC	0.66					
8	Mismatch: Amplifier to CDN	-1.160	dB	U-shaped	1.414	-0.820	0.673
	Amplifier VRC	0.50					
	CDN + 6dB attenuator VRC	0.25					
9	Measurement system repeatability	0.50	dB	Normal (1)	1.000	0.500	0.250
						$u_c(y)$	$\Sigma u_i(y)^2$
						⇐	
10	Combined standard uncertainty		dB	Normal		1.454	2.115
	Expanded uncertainty		dB	Normal, k = 1.64		**2.39**	

To be entered	▨
Calculated	🟧

Test level multiplier for 95% confidence		Antilog(2.39dB/20)		1.316	
Revised test level	For:	3	V	3.95	V
		10	V	13.16	V

This table applies to tests done in accordance with IEC 61000-4-6 with a coupling-decoupling network (CDN). The stress voltage is calibrated into a 150 ohm load and then the same signal generator setting is re-played with the EUT connected. Forward power is not monitored.

As with the radiated test, it is controversial as to whether or not the resulting expanded uncertainty value should be added to the applied stress value.

If it is not added in, so that, say, the stress level is set to 3V, then the implication is that there is no more than a 50% confidence that the specification stress level has been applied. If it is added (stress set to 3.95V in the above example) then there is 95% confidence that the EUT has been tested to at least the specification level. On the other hand, EN 61000-4-6 at paragraph 6.4.1 gives a tolerance on the set level of ± 2 dB or 25%. It is not clear that this is intended as a description of the expanded uncertainty. But if you wish to benefit from this allowed tolerance in the specification, it would only be necessary to add in an extra 0.39dB (for the above example).

Notes

1. Voltage level monitor: this will be the uncertainty of calibration as reported on the voltmeter or power meter calibration certificate
2. 50-to-150 ohm adaptor: the resistive adaptor will usually be verified rather than formally calibrated, this contribution quantifies how far it is from the ideal 100 ohms
3. Voltage level setting window: the test software will have a preset window around the calibration field strength value within which the applied level is acceptable
4. Signal source drift: error in the amplifier output, as between the calibration and the test, due to signal generator and amplifier gain drifts
5. Amplifier harmonics: a contribution from the inclusion in the voltage measurement of harmonics due to amplifier non-linearity
6. Effect of layout variations: uncontrolled deviations in the layout of the cables to the EUT, and the EUT's position, will cause effects which will be greatest at the upper frequency end; this contribution should be assessed by experience
7. Mismatch, CDN to voltage monitor: during calibration, a mismatch error occurs at the voltage meter input due to the non-zero VRC of the CDN-plus-adaptor impedance, which equates to 250 ohms; the voltage meter input VRC is here taken as a typical value
8. Mismatch, Amplifier to CDN: this mismatch contribution is not common to both calibration and test because the impedance at the CDN's RF port depends on the EUT, with a maximum possible VRC of unity, reduced by the 6dB attenuator. The amplifier output VRC is here taken as a typical value
9. Measurement system repeatability: this Type A contribution is derived from multiple investigative measurements using a representative set-up without an EUT

Conducted RF immunity (EM-clamp)

Conducted immunity measurement 150kHz – 80MHz using EM-clamp

	Contribution	Value		Prob. dist.	Divisor	$u_i(y)$	$u_i(y)^2$
1	Voltage level monitor	0.40	dB	Normal	2.000	0.200	0.040
2	50-to-150 ohm adaptor	0.10	dB	Rectangular	1.732	0.058	0.003
3	Voltage level setting window	0.50	dB	Rectangular	1.732	0.289	0.083
4	Signal source drift	0.20	dB	Rectangular	1.732	0.115	0.013
5	Amplifier harmonics	0.70	dB	Rectangular	1.732	0.404	0.163
6	Effect of AE impedance	1.00	dB	Rectangular	1.732	0.577	0.333
7	Effect of layout variations	2.00	dB	Rectangular	1.732	1.155	1.333
8	Mismatch: Clamp to monitor	-1.412	dB	U-shaped	1.414	-0.998	0.996
	Voltmeter VRC	0.20					
	Clamp VRC	0.75					
9	Mismatch: Amplifier to Clamp	-0.819	dB	U-shaped	1.414	-0.579	0.336
	Amplifier VRC	0.50					
	Clamp + 6dB attenuator VRC	0.18					
10	Measurement system repeatability	0.50	dB	Normal (1)	1.000	0.500	0.250
						$u_c(y)$	$\Sigma u_i(y)^2$
							⇐
11	Combined standard uncertainty		dB	Normal		1.885	3.552
	Expanded uncertainty		dB	Normal, k = 1.64		**3.09**	

To be entered	▨
Calculated	🟧

Test level multiplier for 95% confidence		Antilog(3.09dB/20)		1.427	
Revised test level	For:	3	V	4.28	V
		10	V	14.27	V

As in the previous table, the above applies to tests done in accordance with IEC 61000-4-6, but with an EM-clamp. The stress voltage is calibrated into a 150 ohm load and then the same signal generator setting is re-played with the EUT connected. Forward power is not monitored.

The same considerations apply to use of the resulting expanded uncertainty value.

Notes

1. Items 1 – 5, and 7-10 apply as for the previous example with a CDN. The mismatch contributions are different because of the different transducer, but the principle is the same. The harmonics may be slightly more significant because of the higher loss of the clamp, requiring more power for a given injection level.

2. Item 6, Effect of AE impedance: this contribution is the major difference between the CDN method and either of the clamp methods. With a CDN, the effect of variations in the impedance on the AE side of the CDN is negligible. This is not so for either the EM-clamp or the current injection probe. At frequencies below about 10MHz the EM-clamp has negligible directivity; the directivity improves to between 10 and 20dB above 10MHz but this still only results in partial decoupling of the AE. The current injection probe has no directivity at all. The standard requires that the AE impedance is maintained at 150 ohms but this is often impractical. The figure used as a budget contribution here reflects variations of the AE impedance over a 2:1 range with a fixed EUT impedance of 150 ohms.

3. Clause 7.3 of IEC 61000-4-6 requires monitoring of the induced current if the AE common mode impedance cannot be met, with the current limited to a maximum value. A separate uncertainty budget is required for this procedure.

Transients

A serious problem with creating an uncertainty budget for transient immunity tests is that the interaction between the various time and amplitude parameters specified for the generators is impossible to analyse in such a way as to derive an overall expanded uncertainty for the applied stress. In addition, effects such as variations in layout and coupling impedances may add contributions which are again immune to analysis.

On the other hand, each of the main test standards specifies tolerances on the generator parameters and gives instructions for test setup and layout. In this case, ISO 17025 (the standard for accreditation) states that the requirement to estimate uncertainty can be considered to have been satisfied by following the test method and its reporting instructions. It is then only necessary to ensure that the test generator actually used does in fact comply with the standard's requirements, and to ensure that the required reporting format is followed.

This approach is taken for the following three test methods. It is consistent with that given in LAB 34.

EFT Burst

EFT Burst measurement

Applied level **+1 kV**

	Standard requirement		Cal cert value	Calibration uncertainty	Check
V_{PK} (V)	±Tol %	10		3	
	Min	0.9		1.00	OK
	Nominal	**1**	1.03		
	Max	1.1		1.06	OK
t_r (ns)	±Tol %	30		5	
	Min	3.5		5.32	OK
	Nominal	**5**	5.6		
	Max	6.5		5.88	OK
t_{50} (ns)	±Tol %	30		3	
	Min	35		61.60	OK
	Nominal	**50**	63.5		
	Max	65		65.41	**NOT OK**
F_{rep} (kHz)	±Tol %	20		2	
	Min	4		4.80	OK
	Nominal	**5**	4.9		
	Max	6		5.00	OK

Test carried out to IEC 61000-4-4. The four parameters above are required to be verified by clause 6.1.2 of the standard.

ESD

ESD measurement

Applied level **+4 kV**

	Standard requirement		Cal cert value	Calibration uncertainty	Check
I_{PK} (A)	±Tol %	10		5	
	Min	13.5		13.87	OK
	Nominal	**15**	14.6		
	Max	16.5		15.33	OK
I_{30ns} (A)	±Tol %	30		5	
	Min	5.6		6.77	OK
	Nominal	**8**	7.13		
	Max	10.4		7.49	OK
I_{60ns} (A)	±Tol %	30		5	
	Min	2.8		4.09	OK
	Nominal	**4**	4.3		
	Max	5.2		4.52	OK
V_{IND} (kV)	±Tol %	5		2	
	Min	3.8		3.94	OK
	Nominal	**4**	4.02		
	Max	4.2		4.10	OK
t_r (ns)	±Tol %			5	
	Min	**0.7**		0.69	**NOT OK**
	Nominal		0.73		
	Max	**1.0**		0.77	OK

Test carried out to IEC 61000-4-2. The five parameters above are required to be verified by clause 6.2 of the standard.

Surge

Surge measurement (1.2/50µs V, 8/20µs I)

Applied level **+1 kV**

	Standard requirement		Cal cert value	Calibration uncertainty	Check
$V_{PK\text{-}OC}$ (V)	±Tol %	10		3	
	Min	0.9		0.96	OK
	Nominal	**1**	0.99		
	Max	1.1		1.02	OK
t_{front} (µs)	±Tol %	30		3	
	Min	0.84		1.02	OK
	Nominal	**1.2**	1.05		
	Max	1.56		1.08	OK
t_{50} (µs)	±Tol %	20		3	
	Min	40		55.29	OK
	Nominal	**50**	57		
	Max	60		58.71	OK
$I_{PK\text{-}SC}$ (A)	±Tol %	10		3	
	Min	450		470.45	OK
	Nominal	**500**	485		
	Max	550		499.55	OK
t_{front} (µs)	±Tol %	20		3	
	Min	6.4		7.08	OK
	Nominal	**8**	7.3		
	Max	9.6		7.52	OK
t_{50} (µs)	±Tol %	20		3	
	Min	16		21.34	OK
	Nominal	**20**	22		
	Max	24		22.66	OK

Test carried out to IEC 61000-4-5. The six parameters above are required to be verified by clause 6.1.1 and 6.1.2 of the standard.

Notes

The spreadsheet for these three budgets is set out so as to compute the acceptable limits for each parameter from the data in the standard; then to take the actual calibration value from the calibration certificate for the instrument and derive the limits to this value from the quoted calibration uncertainty. Each of these upper and lower limits are then compared to the standard limits to show that the generator's characteristics, reduced by the calibration uncertainty, do comply with the standard.

A computation should be carried out for each of the calibrated conditions of the generator, typically for each polarity at each of the four test levels.

If, as given for example in the red shaded boxes marked “NOT OK” in the above tables, the values are outside the specification limits, the laboratory has three options:

- adjust the generator to bring it within specification;
- choose a calibration laboratory with tighter control of its own uncertainties;
- or, report to the client a compliance statement with a reduced confidence level.

It may not always be possible to demonstrate that a generator is within the tolerances required by the standard because of the magnitude of the uncertainties available from calibration laboratories.

Harmonics and flicker uncertainties

Uncertainty budget examples for these tests have not at the time of writing been published elsewhere, but it is possible to look at the major contributions and give some guidance. The harmonics test is performed to IEC 61000-3-2, applicable to all equipment classes. No attempt is made to account for contributions due to fluctuating harmonic content. The flicker test is performed to IEC 61000-3-3.

Mains harmonic emissions measurement 0-2kHz

	Contribution	Value		Prob. dist.	Divisor	$u_i(y)$	$u_i(y)^2$
1	Analyser calibration	5.00	%	Normal	2.000	2.500	6.250
2	Power source	2.50	%	Rectangular	1.732	1.443	2.083
3	Power source voltage distortion	0.50	%	Rectangular	1.732	0.289	0.083
4	Voltage sensing transducer	0.20	%	Rectangular	1.732	0.115	0.013
5	Ohmic heating	0.75	%	Rectangular	1.732	0.433	0.188
6	Measurement system repeatability	2.00	%	Normal (1)	1.000	2.000	4.000
						$u_c(y)$	$\Sigma u_i(y)^2$
7	Combined standard uncertainty		%	Normal		3.552	12.618
	Expanded uncertainty		%	Normal, k = 2.0		**7.10**	

To be entered	▨
Calculated	🟧

Voltage fluctuations (flicker) measurement

	Contribution	Value		Prob. dist.	Divisor	$u_i(y)$	$u_i(y)^2$
1	Analyser calibration	1.00	%	Normal	2.000	0.500	0.250
2	Power source	2.00	%	Rectangular	1.732	1.155	1.333
3	Power source voltage distortion	0.00	%	Rectangular	1.732	0.000	0.000
4	Reference impedance	5.00	%	Rectangular	1.732	2.887	8.333
5	Ohmic heating	1.50	%	Rectangular	1.732	0.866	0.750
6	Measurement system repeatability	2.00	%	Normal (1)	1.000	2.000	4.000
						$u_c(y)$	$\Sigma u_i(y)^2$
7	Combined standard uncertainty		%	Normal		3.830	14.667
	Expanded uncertainty		%	Normal, k = 2.0		**7.66**	

To be entered	▨
Calculated	🟧

Notes

1. Analyser calibration: taken from the calibration certificate, if available. The harmonics standard requires the system to exhibit a total error of better than 5% of the permitted limit or 0.2% of the EUT rated current. Calibration should verify this performance.

2. Power source: the output impedance should be "sufficiently low to suit the test requirements" but will not be zero, and the output voltage is allowed to vary by up to 2% during the test. The total figure is an estimate based upon measurements of output waveform with a distorting load at the maximum harmonic content allowed by the Class A limits.

3. Power source voltage distortion: separate from source impedance, this is the effect on the measurement due to the finite sine-wave distortion allowed by clause A.2.c) in the standard. This distortion can be verified by measuring a purely resistive load.

4. Voltage sensing transducer: for some instruments this contribution may be incorporated in the specification of the analyser. In other cases it will be based on the accuracy specification of the transducer (current shunt, transformer or Hall effect device).

5. Ohmic heating: derived from a consideration of thermal drift at high currents in the transducer, or for flicker, in the reference impedance and associated wiring. May be neglected if high power EUTs are not tested.

6. Measurement system repeatability: Type A contribution derived from multiple investigative measurements using a representative set-up.

7. Reference impedance: for the flicker measurement, the standard allows a total error in voltage deviation not exceeding 8%. This will be divided between the reference impedance, the analyser and other sources. Since the analyser is measuring only a relative voltage change, its accuracy will be dominated by resolution errors. The major contribution is taken up by errors in the reference impedance, which may include the wiring between source, impedance setting device and the measurement point. Contributions due to the power source output impedance may alternatively be included here.

References

[1] *The expression of uncertainty in EMC testing*, UKAS Publication LAB 34, Edition 1, 2002

[2] *Guide to the Expression of Uncertainty in Measurement*, ISO/IEC/OIML/BIPM (Prepared by ISO/TAG 4/WG 3: January 1993)

[3] *Specification for radio disturbance and immunity measuring apparatus and methods - Part 4: Uncertainty in EMC Measurements*, CISPR/A/355/FDIS (draft CISPR 16-4), IEC, March 2002; standard published in June 2002

[4] *Calibration and use of artificial mains networks and absorbing clamps,* T Williams, G Orford, DTI-NMSPU Project FF2.6 Final Report, Schaffner- Chase EMC Ltd, 1999

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