# Uncertainties of immunity measurements

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## Executive summary and best practice guide

# Executive summary

Headings underlined in blue are hyperlinks to the main report.

## 1. Purpose and method of the project

For testing immunity of electronic products from environmental RF stress, methods described in two complementary international standards and their European equivalents are used:

- IEC 61000-4-3, for radiated fields from 80MHz to 1GHz (2GHz);
- IEC 61000-4-6, for conducted disturbance induced by radiated fields, from 150kHz to 80MHz (230MHz).

Despite their status as international standards, these methods are known to suffer from considerable uncertainties, partly because of variations in the applied stress and partly because of the unpredictable ways in which the equipment under test (EUT) reacts to this stress. The technical aspects of these problems are evaluated in this NMS project.

These uncertainties can be categorised as follows:

- The applied stress for conducted testing depends on the choice of transducer;
- Once the transducer has been selected, the applied stress is determined not only by the construction of the coupling source, the cable and the EUT and associated equipment but also by the physical layout of the test set-up.
- For radiated immunity measurements one important source of uncertainty is the anechoic chamber in which the test is performed. If using different chambers gives different results, this variability should be included in the uncertainty budget and would need to be linked to a 'Quality' factor for the chamber;
- The stress induced in the EUT structure by radiated testing depends on the relative geometry of the field and structure, which are affected by the EUT design and the layout of the test set-up.
- Once internal disturbing signals are generated within the EUT, their interaction with the circuit operation may be non-linear, and therefore the EUT response is affected both by this non-linearity and the uncertainty of induced disturbance.

These factors have been investigated by practical and theoretical analysis and their contributions quantified as far as possible. Comparisons have been made between the three allowed transducer types, and between likely setup variations, for the conducted test. For the radiated test, analyses of the variations between chambers, the coupling of the EUT with the antenna, and the effect of cable configuration have been performed. Investigations of the contribution due to EUT non-linearities has centred on the response of typical electronic devices to external RF stress. Measurements made on surrogate EUTs have confirmed where appropriate the assumptions and methods used in modelling the various aspects.

## 2. Findings for conducted immunity

### CDN method

- The CDN method  is unequivocally more reliable than either of the clamp methods and justifies its choice as the reference method.
- Sensitivity to cable length and layout variations is largely confined to frequencies above 80MHz.

### EM-clamp method

- If the AE common mode impedance $Z_{AE}$ is maintained at 150Ω the EM-clamp is only slightly more sensitive than the CDN to variations in cable length and layout, but a large mismatch (high or low impedance) at the AE increases the sensitivity to cable length and layout changes.
- Variations in $Z_{AE}$ from 150Ω are directly correlated to changes in the applied stress below 2MHz, but above this frequency their impact reduces and it is limited to less than 10dB for shorter cable lengths above 10MHz.

### Current injection probe method

- If the $Z_{AE}$ is maintained at 150Ω the current probe is only slightly more sensitive than the CDN to variations in cable length and layout, up to 26MHz, but above this variations in length and layout can give up to 15dB variation.
- Effects due to cable offset through the probe window are generally negligible unless the AE or EUT have a high impedance.
- A large mismatch (high or low impedance) at the AE increases the sensitivity to cable length and layout changes to about 10dB for frequencies up to 80MHz, and substantially more above this.
- Variations in $Z_{AE}$ from 150Ω are directly correlated to changes in the applied stress from 150kHz to 26MHz, above which frequency standing waves on the cable cause potentially much larger changes in stress.
- The turns ratio of the probe has little effect unless it is as low as 1:1 and the probe is calibrated in a 50Ω system, in which case a roughly 2dB systematic error is introduced by comparison with the CDN reference level.

### Equivalence of the three methods

- If the $Z_{AE}$ is maintained accurately at 150Ω then all three transducers give very similar results. Any departure from $Z_{AE}$ of 150Ω causes a deviation in the injected stress corresponding to the ratio of the total impedances for each of the clamp methods – less for the EM-clamp at high frequencies – but no change for the CDN.

## 3. Findings for radiated immunity

### Chamber performance

- The chamber construction makes an appreciable difference to the range of field values and it is helpful to have a quality factor to describe this range. We discuss the generation of such a factor (the NSD). This is evaluated by computing the mean and standard deviation of all measured fields in V/m (for the 16 field points in both polarisations and for all frequencies). NSD is then defined as:

$$NSD = 20 \, Log_{10} \, (\text{standard deviation / mean})$$

### Uncertainties due to under-testing

- Using the NSD, the likely uncertainties due to under-testing because of field non-uniformity can be estimated for a given chamber. Alternatively, a more accurate assessment can be derived from actual field uniformity figures.
- The level setting method proposed in 77B/352/FDIS is a substantial improvement on the previous standard and should be adopted as quickly as possible.

### Uncertainties due to antenna coupling effects

- Uncertainties due to antenna-to-EUT coupling have been found to approach 1.5 dB. At closer distances than 3m a higher value should be expected.

### Uncertainties due to cable layout

- Uncertainties due to cable layout variations that are not controlled within the standard method may be of the order of 20dB or greater. Some recommendations are needed to control this source.

## 4. EUT effects

### Digital circuits

- The response of a digital system to interference is inherently non-linear and stochastic. No direct relationship between the uncertainty of the applied stress and the uncertainty of the compliance outcome can be established.

### Analogue circuits

- As with digital systems, the connection between uncertainty of applied stress and uncertainty of response cannot be stated in general.
- Overall, it is not generally feasible to make a statement of uncertainty about the result of a radio frequency immunity test. Only the uncertainty of the applied stress can be quoted.

## 5. Recommendations for further work

The procedure of IEC 61000-4-6 para 7, for application when the AE common mode impedance requirements cannot be met, has the potential to introduce substantial extra sources of uncertainty. These should be investigated fully.

The work described here has taken only one type of EUT as its model. While the model was chosen to represent a large class of EUT types, generalisation of the results to many other types (larger or smaller) would be dangerous without further work to ensure that the model is valid.

For radiated immunity, the results suggest that considerable extra work on coupling to cables, both modelled and practical, would be justified. Further work on refining the NSD parameter to describe chamber performance would also be worthwhile.

# Best practice guide

The investigations of this project have resulted in a number of recommendations to test laboratories to improve the repeatability of RF immunity testing to IEC 61000-4-3 and IEC 61000-4-6. These are presented in this section.

## 1. Conducted immunity to IEC 61000-4-6

### Preferred method

**The CDN method is to be preferred in all cases.** This is because its decoupling from the associated equipment (AE) is virtually total, so that neither common mode impedance effects nor interference susceptibility effects attributable to the AE need be considered.

The CDN also has the least path loss of the three methods; this means either that a greater stress level can be achieved for a given amplifier power, or that uncertainties due to amplifier limitations can be minimised.

The clamp methods should only be considered where a CDN is impractical or would affect the required signal path unacceptably. Laboratories should be encouraged to maintain a stock of CDN types appropriate to their EUTs.

### Ground bonding

**Proper ground bonding methods should be observed for CDN and EM-clamp.**

The impedance of the ground bond appears in series with the coupling transducer's common mode impedance. Since the frequency range is normally up to 80MHz and may extend up to 230MHz in some cases, the bond impedance must be satisfactorily low up to these frequencies. This means that direct contact should be maintained between the test ground plane and the transducer ground terminal (normally a plate) with, preferably, a secondary bonding strap to ensure DC continuity in the presence of surface oxides.

### AE common mode impedance

For either clamp method:

- **The requirement to maintain $Z_{AE}$ at 150Ω must be strictly observed, or else section 7.3 in the standard must be properly applied**
- **cable lengths should be as short as possible, and the total length should be less than 1m**
- **if longer cables are essential, the EM-clamp method should be used.**

Both clamp methods are susceptible to errors introduced from an uncontrolled AE common mode impedance ($Z_{AE}$), and these errors can be dramatic. The standard includes the requirement in clause 7.2 to maintain $Z_{AE}$ at 150Ω but this is not a simple matter if the AE is large and has several connections. A small AE with a single (e.g. mains power) connection can be stabilised with a CDN-M3 and this should always be provided as a matter of course. If other cables leave the AE they should be decoupled to a high impedance with ferrite clamp devices (that must be effective down to 150kHz).

These cables at the AE side of the clamp may still resonate (for instance a 2m length has a quarter wave resonant frequency of 37.5MHz) and therefore with longer cables provision to maintain the AE's own CM impedance may not be adequate. The EM-clamp provides reasonably effective decoupling above 10MHz and therefore will deal with this problem, although it is still necessary to maintain 150Ω at the lower frequencies where this decoupling is not evident. The current injection probe gives no such decoupling and is therefore not suitable for long cables.

### Cable configuration above 80MHz

**For all methods, the errors introduced from 80 to 230MHz are very much greater than those below it, and accurate recording of cable layout, length and termination are essential**. This should include a measurement of the height above the ground plane (from 3 to 5cm can make several dB difference), a measurement of the length from the EUT connector to the edge terminals of the CDN or the edge of the EM-clamp (from 10 to 30cm can make several dB difference), and a description of the type of cable and its connectors.

Annex B of IEC 61000-4-6, "Selection criteria for the frequency range of application", includes the statement

> "When using this test method up to higher frequencies, results are influenced by: the size of equipment, the type(s) of interconnecting cables used, and the availability of special CDNs, etc. Further guidance for proper application should be supplied in the dedicated product standards."

The main product standard which extends the frequency range to 230MHz is CISPR 14-2/EN 55014-2. No such guidance appears in its text. The records described above are therefore crucial to allow a repeatable test.

### Use of current probe for high frequency compliance tests

**The current injection probe method in particular is so susceptible to errors from 80 to 230MHz that its use should be avoided for compliance tests**, and only the CDN or EM-clamp methods should be allowed in this range. These errors are primarily caused by cable resonance effects which are impossible to avoid in this frequency range except with unrealistically small test setups.

The EM-clamp and CDN decouple the cable length to the AE and therefore the problem is restricted to the cable between the transducer and the EUT. This length is usually manageable and, although uncertainties due to cable layout are larger, they can normally be accepted.

### Current probe construction

**Any current probe turns ratio greater than 2:1 is acceptable; if a 1:1 ratio probe is used this will not meet the insertion loss requirement, and it may only be calibrated in a 150Ω system, not 50Ω**. For the 1:1 probe calibrated in a 50Ω system, there is a systematic increase from the CDN method of 1.5 – 2.5dB above about 2MHz, the frequency at which the probe coupling flattens out to its maximum. The differential is slightly higher for a higher impedance EUT. There is much less differential when the probe is calibrated in a 150Ω system.

This systematic error is easily explained by considering the extra insertion impedance introduced by the 1:1 probe, which is proportionally greater in the 50Ω system.

## 2. Radiated immunity to IEC 61000-4-3

### Use of NSD

To understand the impact of chamber construction on the stress level uncertainty it is necessary to calculate the chamber Normalised Standard Deviation (NSD). **Using the NSD, the likely**

**uncertainties due to under-testing because of field non-uniformity can be estimated for a given chamber** using the information in this report. A more thorough approach is to use actual field uniformity figures to show the frequencies and locations at which under-testing is expected. This information can then be used to assess and if necessary modify the testing approach in situations which appear to be marginal for compliance.

## Test level setting procedure

The field stress level is set using an algorithm given in clause 6.2 of IEC 61000-4-3. This is usually implemented in the control software. The algorithm is not entirely precise, and it is not always clear exactly how the software interprets it. This could lead to different test levels being applied even within the same chamber and with identical equipment.

**The new method proposed in 77B/352/FDIS, which revises clause 6.2, is a substantial improvement on the previous standard and should be adopted as quickly as possible.** Laboratories should contact their software supplier to investigate the possibility of upgrading.

## Cable layout

Uncertainties due to cable layout variations that are not controlled within the standard method may be of the order of 20dB or greater. These variations include the cable length, layout with respect to the chamber floor and walls and antenna polarisation, and termination to the chamber floor or wall when the signal must pass out of the chamber. All cables are relevant since they affect the common mode impedance at the EUT, especially when this is a small table-top unit.

**To deal with this source, the test report must state clearly the actual configuration tested, including the length, exact layout and termination method for each cable.**

There is some evidence that terminating cables with an appropriate CDN to the chamber wall or floor, rather than leaving them short- or open-circuit, reduces the range of variations that may be seen.