The Expanded Uncertainty for Radio Frequency Immunity Testing

Rafał Przesmycki, Leszek Nowosielski, Marian Wnuk, and Roman Kubacki
Faculty of Electronics, Military University of Technology, 2 Gen. S. Kaliski str., Warsaw 00-908, Poland

Abstract—This paper is concerned with the problems of electromagnetic compatibility for RF (Radio Frequency) immunity testing according to the EN 61000-4-3 standard. The measurement uncertainty budget calculation techniques recommended in standardizing documents are barely described and very often they are not adapted to the specific needs of tests performed within the scope of EMC (Electromagnetic Compatibility). The authors focused attention on presentation of the measurement uncertainty budget calculation algorithm. The information related to measurement uncertainty of RF signal test level setting during the RF immunity test in an anechoic chamber are presented. The example of uncertainty budget for laboratory stand used by accredited EMC laboratory for RF immunity testing of information technology equipment is precisely described too.

1. INTRODUCTION

EMC (Electromagnetic Compatibility) testing is a process of taking measurement. 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 measurement are no different in this respect. But the subject of measurement uncertainty in EMC tests is more complex than most.

EMC test standards include a specification of what has to be measured and define a method for measuring it. For any given electromagnetic field strength measurement method, there are usually several sources of measurement uncertainty, although only one or two may dominate. Each individual source has to be analysed. A values to each of these sources have to be assigned and then summed using an appropriate manner to give the total measurement uncertainty.

2. IMMUNITY TEST ACCORDING THE EN 61000-4-3 STANDARD

The EN 61000-4-3 standard is applicable to the immunity requirements of electrical and electronic equipment to radiated electromagnetic energy. It establishes test levels and the required test procedures.

Above standard requires a radiated RF field generated by an antenna in a shielded anechoic chamber enclosure using a pre-calibrated field, swept from 80 MHz to 1000 MHz with the step size not exceeding 1% previous frequency and dwell time sufficient to allow the EUT (Equipment Under Test) to respond. The antenna faces each of the four sides of the EUT in each polarization, hence there are minimum 8 tests in all. In order to assure of the generated field uniformity the anechoic chamber is required or another alternative test sites. Severity levels are unmodulated and has to be level 1, 3 or 10 V/m. The actual applied signals is modulated to 80% with a 1 kHz sine wave.

3. MEASUREMENT UNCERTAINTY COMPONENTS OF THE MEASURAND

The measurand is the hypothetical test field strength (without an EUT) at the point of the UFA (Uniform Field Area) selected according to the field calibration process. The diagram shown in Figure 1 describes the measurement uncertainty components on the resultant uncertainty in level setting.

The diagram applies to calibration and test processes and it is not exhaustive. The most important measurement uncertainty components have to be selected for the uncertainty budget. As a minimum, the components listed in the example uncertainty budget (see Chapter 5) shall be used for the calculation of the uncertainty budgets in order to get comparable budgets for different test sites or laboratories. It is noted that a laboratory may include additional components in the calculation of the measurement uncertainty, on the basic of its particular circumstances.
4. UNCERTAINTY BUDGET

An uncertainty budget lists the most likely error sources and individually estimates 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 of the components — if a particular component turns out to be negligible, it is still better to acknowledge its presence and include it at a low value than to ignore a component that may increase the resultant uncertainty significantly. Once you have analyzed each component, the individual components are summed to produce the final result for the measurement. Un during the analysis, sources of uncertainty can be grouped into one of two categories A or B based on their method of evaluation.

4.1. Type a Method

Type A method 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. 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 general case, you will be testing many different types EUT and it is rarely practical to perform many repeat measurements on each type. Therefore the Type A method that is analyzed in this way does not include a contribution for random variation due to 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 determination of the uncertainty due to random contributions is given by the standard deviation $s(q_k)$ of a series of $n$ 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. The $s(q_k)$ value is used directly for the uncertainty budget calculations 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 for frequencies that are critical. In this case, the uncertainty is reduced in the way described by the following formula:

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

So that four repeat measurement on the EUT, will halve the uncertainty due to random effects. Note that this has no effect on other contributions, which are analyzed 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.
4.2. Type B Method

Type B evaluation is done by means other that used for Type A, for example, data from calibration certificates, previous measurements, manufacturers specifications or an understanding of instrument behavior, or other relevant information. It applies to systematic effects which remain constant during the measurement but which may change if the measurement conditions, method or equipment are altered. Equipment calibration, mismatch errors, and 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 value either from the manufacturer’s specification — or take a maximum error from the calibration certificate, extended by the calibration uncertainty, and apply that.

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.

4.3. Summation of Two Methods

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 manufacturer’s 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 the point between two limits increases uniformly from zero at the extremities to the maximum at the center; should be assigned where the majority of the values between the limits lie around the central point.

The distributions describes the variation in probability of the true value lying at any particular difference from the measured result. It’s 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

![Figure 2: Probability distribution.](image_url)
forms. You can then calculate the standard uncertainty \( u(x_i) \), for the assigned form from simple expressions (see Figure 2). If a particular uncertainty contribution is not in the same units as the required total uncertainty then strictly speaking the contribution should be converted using a “sensitive coefficient” \( c_i \). This then gives a series of output contributions \( u_i(y) \). Practically, it is easier to leave the sensitive 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:

\[
    u_c(y) = \sqrt{\sum_{i=1}^{m} u_i^2(y)} \tag{3}
\]

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 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 95% is usual for industrial and commercial measurement.

5. CALCULATION EXAMPLES FOR EXPANDED UNCERTAINTY

In this chapter is described example of how to set up an uncertainty budget for EMC immunity tests. It must be recognized that the contributions that apply for UFA calibration and for immunity test process may not be the same. This leads to different uncertainty budget for each process. Tables 1 and 2 give examples of an uncertainty budget for level setting. The uncertainty budget consist of two parts, the uncertainty for calibration and the uncertainty for test.

In above tables are used fallsows symbols: \( \text{FP} \) is a combination of calibration uncertainty, field probe unbalance (anisotropy), field probe frequency response and temperature sensitivity. Normally

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Uncertainty Source X</th>
<th>( u(x_i) )</th>
<th>Unit</th>
<th>Distribution</th>
<th>Diverter</th>
<th>( u(y) )</th>
<th>Unit</th>
<th>( u_i(y) )</th>
<th>Unit</th>
<th>( u_i^2(y) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP</td>
<td>Field Probe Calibration</td>
<td>1.60</td>
<td>dB</td>
<td>Normal</td>
<td>2</td>
<td>2</td>
<td>0.66</td>
<td>dB</td>
<td>0.66</td>
<td>0.65</td>
</tr>
<tr>
<td>PMA</td>
<td>Power Meter</td>
<td>0.30</td>
<td>dB</td>
<td>Rectangular</td>
<td>3</td>
<td>1.73</td>
<td>0.17</td>
<td>dB</td>
<td>0.17</td>
<td>0.02</td>
</tr>
<tr>
<td>PAG</td>
<td>PA rapid gain variation</td>
<td>0.20</td>
<td>dB</td>
<td>Rectangular</td>
<td>3</td>
<td>1.73</td>
<td>0.12</td>
<td>dB</td>
<td>0.12</td>
<td>0.01</td>
</tr>
<tr>
<td>SWP</td>
<td>SW leveling precision</td>
<td>0.60</td>
<td>dB</td>
<td>Rectangular</td>
<td>3</td>
<td>1.73</td>
<td>0.38</td>
<td>dB</td>
<td>0.38</td>
<td>0.12</td>
</tr>
</tbody>
</table>

\[
\sum u_i^2(y) = 1.07
\]

\[
u_c(y) = \sqrt{\sum u_i^2(y)} = 1.03
\]

Expanded Uncertainty for \( k = 2 \) (level of confidence of 95%).

Table 2: Example of uncertainty budget for level setting.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Uncertainty Source X</th>
<th>( u(x_i) )</th>
<th>Unit</th>
<th>Distribution</th>
<th>Diverter</th>
<th>( u(y) )</th>
<th>Unit</th>
<th>( u_i(y) )</th>
<th>Unit</th>
<th>( u_i^2(y) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>Calibration</td>
<td>2.07</td>
<td>dB</td>
<td>Normal</td>
<td>2</td>
<td>2</td>
<td>0.04</td>
<td>dB</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>AL</td>
<td>Antenna location variation and asorption placement</td>
<td>0.36</td>
<td>dB</td>
<td>( k = 1 )</td>
<td>1</td>
<td>1</td>
<td>0.36</td>
<td>dB</td>
<td>0.36</td>
<td>0.14</td>
</tr>
<tr>
<td>PMA</td>
<td>Power Meter</td>
<td>0.50</td>
<td>dB</td>
<td>Rectangular</td>
<td>3</td>
<td>1.73</td>
<td>0.17</td>
<td>dB</td>
<td>0.17</td>
<td>0.02</td>
</tr>
<tr>
<td>PAG</td>
<td>PA rapid gain variation</td>
<td>0.20</td>
<td>dB</td>
<td>Rectangular</td>
<td>3</td>
<td>1.73</td>
<td>0.12</td>
<td>dB</td>
<td>0.12</td>
<td>0.01</td>
</tr>
<tr>
<td>SWP</td>
<td>SW leveling precision</td>
<td>0.60</td>
<td>dB</td>
<td>Rectangular</td>
<td>3</td>
<td>1.73</td>
<td>0.38</td>
<td>dB</td>
<td>0.38</td>
<td>0.12</td>
</tr>
<tr>
<td>SG</td>
<td>Signal generator stability</td>
<td>0.13</td>
<td>dB</td>
<td>Rectangular</td>
<td>3</td>
<td>1.73</td>
<td>0.08</td>
<td>dB</td>
<td>0.08</td>
<td>0.01</td>
</tr>
</tbody>
</table>

\[
\sum u_i^2(y) = 1.35
\]

\[
u_c(y) = \sqrt{\sum u_i^2(y)} = 1.16
\]

Expanded Uncertainty for \( k = 2 \) (level of confidence of 95%).
Table 3: Example of the test level multiplier for 95% confidence and revised test level.

<table>
<thead>
<tr>
<th>Test level multiplier for 95% confidence</th>
<th>Antilog (2.32dB / 20)</th>
<th>1.306</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revised test level</td>
<td>For:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.92</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>13.06</td>
</tr>
</tbody>
</table>

this data can be obtained from the probe data sheet or calibration certificate. $\text{PM}_{\text{cal}}$ and $\text{PM}_{\text{test}}$ are the uncertainty of the power meter, including its sensor, taken from either the manufacturer’s specification (and treated as a rectangular contribution) or a calibration certificate (and treated as a normal contribution). If the same power meter is used for both calibration and test, this contribution can be reduced to the repeatability and linearity of the power meter. $\text{PA}_{\text{cal}}$ and $\text{PA}_{\text{test}}$ are including the uncertainty derived from rapid gain variation of the power amplifier after the steady status has been reached. $\text{SW}_{\text{cal}}$ and $\text{SW}_{\text{test}}$ are the uncertainty derived from the discrete step size of the frequency generator and software windows for level setting during the calibration process. The software window can usually be adjusted by the test laboratory. $\text{CAL}$ is the expanded uncertainty of the forward power needed to establish the test field strength for calibration. $\text{AL}$ is the uncertainty derived from removal and replacement of the antenna and absorbers. The antenna location variation and absorber placement are type A contributions, i.e., their uncertainty can be evaluated by statistical analysis of series of observation. Type A contributions are normally not part of the uncertainty of measurement equipment, however these contributions were taken into account because of their high importance and their close relation to the measurement equipment. $\text{SG}$ is a drift of the signal generator during the dwell time.

6. CONCLUSION
The calculated expanded uncertainty may be applied to tests done in accordance with EN 61000-4-3 in an 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 how the resulting uncertainty value should be used. In the Table 3 is shown the test level multiplier for 95% confidence and revised test level for described example uncertainty budget.

If it is not added in, so that, say, the stress level is set to 3 V, then the implication is that there is no more than 50% confidence that the specification stress level has been applied. If it is added (stress set to 3.92 V/m in the above example) then is 95% confidence that the EUT has been tested to at least the specification level. Assuming the distribution within the interval is normal, this sets the uncertainty interval to a 95% confidence level, which will then result in a 95% confidence of application of at least the correct stress.

REFERENCES