Field non-uniformity over the uniform field area
as per IEC 61000-4-3 radiated immunity test

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*Abstract-*The scope here is to quantify the non-uniformity of the electric field over the uniform field area as defined in the IEC 61000-4-3 standard for radiated immunity test. To this purpose the electric field intensity data over the 1.5 m x 1.5 m area, provided by nine laboratories, were collected and analysed. The frequency range considered is between 80 and 1000 MHz. It is shown that the non-uniformity is nearly frequency independent and amounts to 1.2 dB in terms of one standard deviation. This figure is meant to represent the average performance expected from a laboratory complying with the – 0 to + 6 dB field-uniformity requirement of the standard and is offered as a reference value useful for uncertainty evaluations.

*Keywords-*Electromagnetic compatibility measurements, measurement uncertainty, radiated immunity, uniform field area.

I. Introduction

ISO/IEC 17025 [1] requires that test laboratories evaluate measurement uncertainty. The sound evaluation of measurement uncertainty is felt essential for providing evidence of technical competence. The requirement applies also to conformity assessment, even though limits and test levels were set taking into account typical values of measurement uncertainty [2]. In the case of Electromagnetic Compatibility (EMC) tests, measurement uncertainty shall be evaluated both for emission and immunity measurements [3, 4].

The evaluation of measurement uncertainty of immunity tests has recently become an issue for the committees in charge of the maintenance and development of the relevant standards. The immunity standards that will first incorporate uncertainty budgets are IEC 61000-4-2 (immunity to electrostatic discharge), -3 (immunity to radiated electromagnetic fields) and -6 (immunity to induced RF current). The quantities subject to uncertainty evaluation are those characterizing the stimulus applied to the equipment under test, such as amplitude and modulation depth (frequency-domain) or rise-time, duration, peak amplitude (time-domain).

This applies in particular to the electric field stimulus generated when testing for compliance with IEC 61000-4-3 [5]. In the 80 to 1000 MHz frequency range the field must be uniform within – 0 to + 6 dB of the stipulated test level in 12 out of 16 equally spaced points over a 1,5 m x 1,5 m square surface, named Uniform Field Area (UFA). Test frequencies are chosen according to a geometric sequence whose ratio is 1,01 (1 % increment). The 12 points of the UFA satisfying the – 0 to + 6 dB uniformity requirement have not necessarily to be the same at each frequency.

Actually, field uniformity is the requisite for compliance of the test facility and instrumentation, however whether including or not the contribution associated to field non-uniformity into the uncertainty budget for the electric field test level is a topic open to debate. Several arguments can be carried for inclusion. First ISO/IEC 17025 states that (paragraph 5.4.6.2) "... the laboratory shall ... attempt to identify all the components of uncertainty and make a reasonable estimation, and shall ensure that the form of reporting of the result does not give a wrong impression of the uncertainty." In addition "Reasonable estimation shall be based on knowledge of the performance of the method and on the measurement scope and shall make use of, for example, previous experience and validation data." Ideally a plane wave, whose intensity is equal to the chosen test level, should be generated at the UFA. However several undesired causes concur to corrupt the uniformity of the field and therefore we have uncertainty about the test level that is actually generated. Hence non-uniformity is a "component of uncertainty". If we neglect such component (particularly when dominant) the uncertainty of the electric field test level may be so small to leave in the user of such information a "wrong impression" about the quality (i.e. closeness to ideal) of the plane wave generated. "Knowledge of the performance of the method" gained through the "validation data" resulting from the procedure of field calibration ([5, section 6.2]) should not be discarded but instead used to derive an estimate of field non-uniformity.

The most suitable and readily available measure of non-uniformity is the standard deviation of the field calculated over the 16 points of the UFA. Since the dispersion is expected to be relatively large, then the electric field readings from the field meter are converted to log-units before the calculation of standard deviation in order

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to avoid non-physical outcomes [6]. Further, by doing so, the calculated dispersion is homogeneous with the other contributions to test level uncertainty, usually expressed in dB.

In order to derive a typical figure of field non-uniformity that can be adopted as a reference by standards committees and laboratories, the electric field intensity data over the UFA provided by nine laboratories were statistically processed. All the laboratories complied with the − 0 to + 6 dB UFA requirement. This is the only selection criterion adopted in order to assure the homogeneity of the sample.

The statistical processing is described in section II. The results of the analysis are presented and discussed in section III. Conclusion follows in section IV.

II. Statistical processing

The nine laboratories provided the following data:

I.   five laboratories provided the electric field intensity generated both in vertical and horizontal polarization at the 16 points of the UFA;

II.   two laboratories provided the electric field intensity at the 16 points along one polarization (without specifying if horizontal or vertical);

III. one laboratory provided the forward power level corresponding to the 16 points of the UFA (at only one polarization) since the constant field calibration technique was adopted by that laboratory;

IV.   one laboratory provided, in the 80 to 200 MHz frequency range, the difference, in dB, between the maximum and the minimum field intensity over the total 16 points of the UFA and over the 12 points satisfying the − 0 to + 6 dB requirement. The laboratory also provided range and standard deviation information between 200 and 1000 MHz. Both vertical and horizontal polarization were covered.
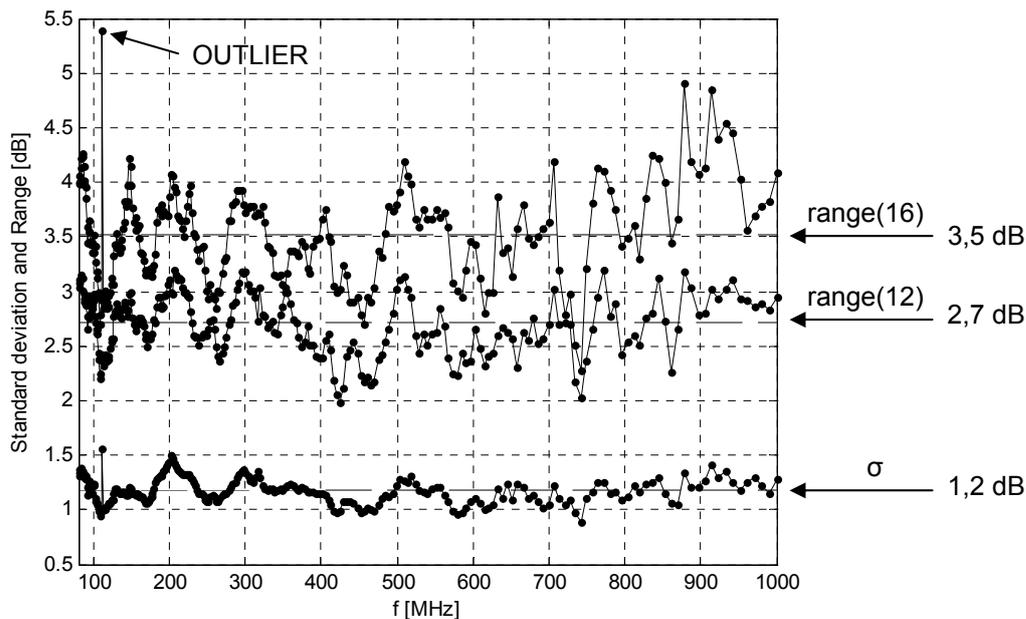

Figure 1. Standard deviation σ and range (over 16 points, range(16), and over 12 points, range(12)) as a function of frequency in the 80-1000 MHz range. Note that σ is nearly independent of frequency and its mean value is 1,2 dB. The ratio d between range and standard deviation is 2,9 (16 points) and 2,3 (12 points). An outlier produced by one laboratory is visible.

In view of the fact that the dispersion over the UFA results to be weakly dependent on the polarization of the electric field, in order to avoid excess of detail it is convenient to average the corresponding standard deviations instead of calculating two different results, one for the vertical polarization and the other for the horizontal one. In addition, since we seek for a typical figure of dispersion, representative of all laboratories, an average standard deviation is calculated from those of the contributing laboratories. The rule that we adopt for calculating the average standard deviation (i.e. between vertical and horizontal polarization for each laboratory and between laboratories) is the *root of the mean of the squares*. Therefore, if $\sigma_{V,n}$ and $\sigma_{H,n}$ represent the standard deviations of the 16 points over the UFA of the n-th laboratory and corresponding to vertical and horizontal polarization,

respectively, then the standard deviation σ_n, representing the dispersion over the UFA of the n-th laboratory, is

$$\sigma_n = \sqrt{\frac{1}{2}\left(\sigma_{V,n}^2 + \sigma_{H,n}^2\right)}. \tag{1}$$

The average standard deviation σ between the M contributing laboratories ($M = 9$ in our case) is

$$\sigma = \sqrt{\frac{1}{M}\sum_{n=1}^{M}\sigma_n^2} \tag{2}$$

We anticipate (see Fig. 1) that σ is almost frequency independent and nearly equal to 1,2 dB.

Since one laboratory provided range information, instead of raw data, it is necessary to derive a coefficient d which permits to obtain the standard deviation, σ_n, from the corresponding range R_n for that laboratory, i.e. $d = R_n / \sigma_n$. In addition since range information is provided on the basis of 16 or 12 points, we have two corresponding coefficients. The coefficient d can be derived in several ways. One way is, for example, to calculate d from the whole data set provided by the participating laboratories, assuming that all the laboratories similarly behave in this respect. The value of d which results from this analysis (see Fig. 1) is about 2,9 for 16-points range, and 2,3 for 12-points range. Another way consists in calculating the coefficient assuming a theoretical parent probability density function. By describing the scattering over the UFA with a Gaussian distribution then

$$d = 2F^{-1}\left(\frac{16-3/8}{16+1/4}\right) = 3,5 \tag{3}$$

for the 16-points range, where F^{-1} represents the inverse of the Normal cumulative distribution ([7, pag. 90]). In the case of the 12-points range d depends on both the parent distribution and the algorithm followed to select the 12 among the 16 points. No analytical formula exists in this case but one can make use of a Monte Carlo simulation in order to numerically derive an estimate. Again, assuming a Gaussian parent distribution and by using the algorithm described in the latest edition of the IEC 61000-4-3 standard [5] it turns out that

$$d = 2,3 \tag{4}$$

Our choice was to use the 16-points range information to derive standard deviation, because this is a self-evident quantity while 12-points range depends on the specific algorithm used. In addition, for sake of generality, we preferred to use the theoretical value of d (i.e. 3,5, see equation (3)) instead of the one based on the available data (i.e. 2,9, see Fig. 1) also considering that the deviation between the two is not large (about 20 %).

III. Results

The results of the statistical processing are shown in Fig. 1, Fig. 2 and Fig. 3. Fig. 1 was presented and discussed in the previous section II. Fig. 2 shows the standard deviation associated to the scattering over UFA of each laboratory, σ_n, and the resulting average standard deviation σ. The dispersion among the traces is confined between 0,3 dB and 2,4 dB. One laboratory produced an outlier, which is reported both in Fig. 1 and in Fig. 2. Its origin was not investigated, mainly because, being clearly identified, it does not affect the results of the analysis.

In order to obtain a measure of the dispersion of the standard deviations plotted in Fig. 2 the standard deviation of the standard deviations (STD) was calculated. The average value of STD over the whole frequency range is 0,4 dB. In Fig. 3 the limits of the interval 1,2 dB $\pm$ 3·0,4 dB are shown together with σ. Finally, if one is interested in obtaining a figure of reliability of the estimate $\sigma = 1.2$ dB then the value of STD can be divided by $\sqrt{9} = 3$ (nine being the number of laboratories), thus obtaining $0,4 / 3 = 0,13$ dB as an estimate of the standard deviation of σ. It can be therefore concluded, with 95 % confidence, that $\sigma = 1,2 \pm 0,3$ dB (where a coverage factor $k = 2$ is used).
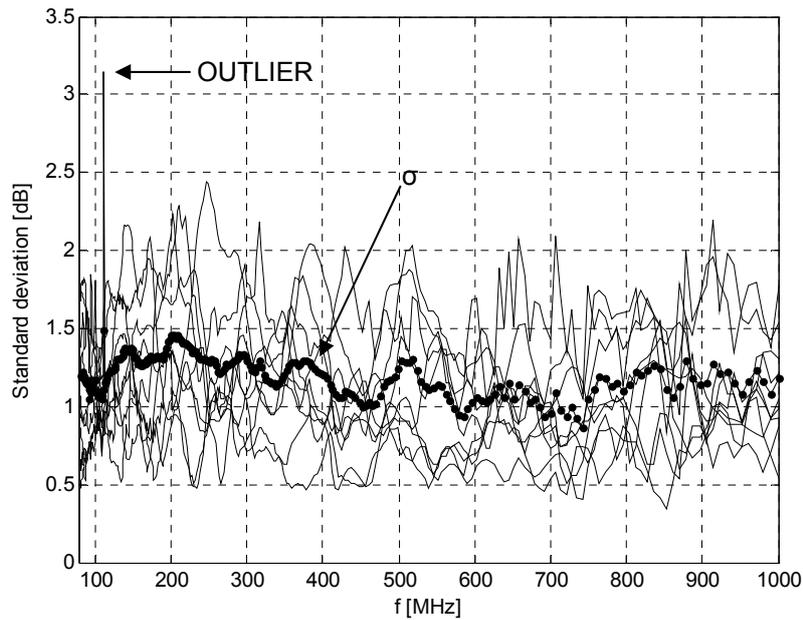
Figure 2. Standard deviation σ_n of the scattering over the UFA for each laboratory (nine traces) and average standard deviation σ (dotted line) as a function of frequency. The same outlier as that appearing in Fig. 1 is here identified.
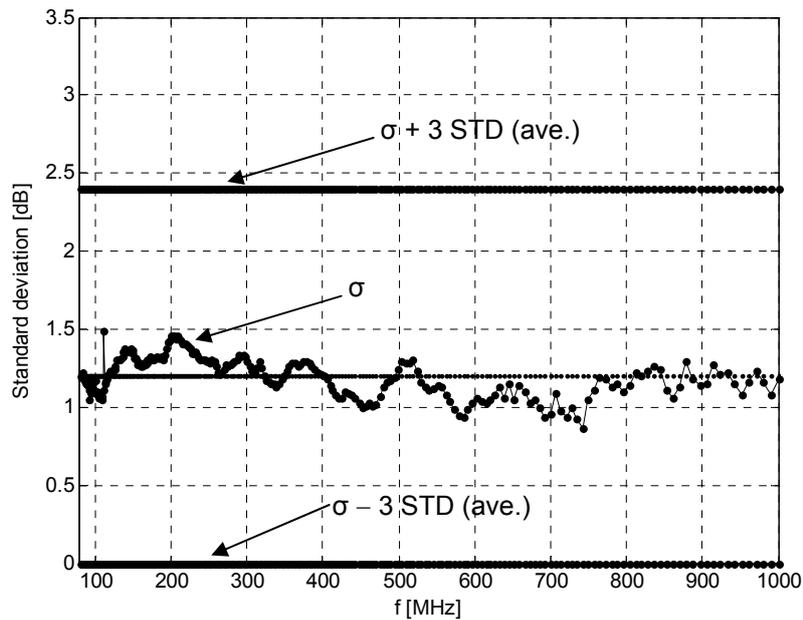

Figure 3. Standard deviation σ and limits $\sigma - 3$STD and $\sigma + 3$STD (limits are in terms of the average values for σ and STD over the whole 80 to 1000 MHz frequency range).

IV. Conclusion

The uncertainty of the stimulus generated while testing for immunity to electromagnetic fields is in part due to the deviation of the electric field from the ideal plane wave distribution. Such deviation can be easily quantified in terms of the standard deviation of the electric field (or forward power, depending on the field calibration technique) over the 16 points of the uniform field area. These data are available to the laboratories since field calibration is a necessary step before testing. If the laboratory cannot access these raw data formulas (see equations (3) and (4)) are here given to derive the standard deviation from the range information over 16 or 12

points of the uniform field area.

We here describe the use of this parameter as restricted to the uncertainty evaluation, however its application can be extended to the choice of the test level (for example in terms of average electric field over the uniform field area) correlating the level to its uncertainty (the larger the uncertainty the larger the level) in a similar fashion to that proposed by CISPR for emission measurements (the larger the uncertainty the smaller the limit). This can be done in the range of test levels where the generation system can be assumed to be linear, or non-linearity does not excessively impact on the uncertainty.

The use of the -0 to $+6$ dB uniformity-based acceptance criterion is not in contrast with the use of the standard deviation over the uniform field area for uncertainty evaluation purposes. Both these quantities can be effectively employed by standards and laboratories. What matters here to stress is that: a) compliance with the acceptance criterion can be achieved with a higher or lower degree of uniformity, b) the degree of uniformity is adequately described by the standard deviation of the field over the uniform field area, and c) the standard deviation of the field over the uniform field area is a fundamental contribution to the combined uncertainty of the test level.

A possible future development of the analysis presented here is the application of analysis of variance techniques in order to identify the sources of within/between variability among laboratories.

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