Uncertainty in RF Disturbance Measurements: Revision of CISPR 16-4-2

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Abstract— **CISPR 16-4-2 is a basic standard that deals with measurement instrumentation uncertainty for RF disturbance measurements. Its 1st edition has become available in 2002 and it is used since 2005 by some product standards. The experience gained with it is positive. As it does not cover all disturbance measurement methods, it is now time for a revision to include further procedures of conducted and radiated disturbance measurements. Special problems of uncertainty are presented.**
Key words: measurement, uncertainty, RF disturbance,

I. INTRODUCTION

The 1st edition of CISPR 16-4-2 [1] was published in 11.2003 being identical with the 1st edition of CISPR 16-4 that was published in 06.2002. Since then it has been applied by product standards (a) Amendment 2:2006-06 [2] to CISPR 11 4th edition and (b) CISPR 22 5th ed:2005-04 [3]. While in the latter standards the amount of uncertainty only has to be stated in the test report, proposals have recently been made for Generic Standards (IEC 61000-6-3 and -6-4) to apply CISPR 16-4-2 to its full extent, i.e. to check whether the test lab's uncertainty U_{lab} exceeds a recommended upper bound U_{cispr} and - if this is true - to stay below the limit by an amount $U_{lab} - U_{cispr}$. At present, the specifications for U_{cispr} apply only to three methods of measurement: to conducted disturbance using the artificial mains network (AMN) from 9 kHz to 30 MHz, to disturbance power measurements using the absorbing clamp from 30 MHz to 300 MHz and to radiated disturbance measurements from 30 MHz to 1000 MHz. Work is now going on to extend the concept of CISPR 16-4-2 also to other methods of measurement.

II. CONCEPT OF CISPR 16-4-2

A. Scope

The standard deals with the estimation and treatment of Measurement Instrumentation Uncertainty (MIU), which includes the uncertainty contributions of the measuring receiver as well as those of the ancillary equipment (connecting cables, transducers such as AMNs, absorbing clamps and antennas) and the test sites including the test geometry, for which the validation criteria play an important role. Not included are uncertainties due to the reproducibility of the Equipment under Test (EUT) as well as of the test specification (e.g. EUT setup, cable arrangement and measurement procedure), which are comprised in the term "Standards Compliance Uncertainty (SCU)".

B. Structure

The standard contains a relatively short normative section which apart from the IEC standardized clauses Scope, Normative References and Definitions contains the basic equations for the calculation of uncertainty U_{lab}, a list of U_{cispr} values and the list of influence quantities to be considered for the estimation. In a detailed informative annex, the background for the U_{cispr} values is given with useful information on the assumptions.

C. Basic Rules

For the measurement uncertainty U_{lab} of a test lab, the standard uncertainties $u(x_i)$ in decibels of each influence quantity and the associated sensitivity coefficient c_i shall be used to calculate the combined standard uncertainty $u_c(y)$ of the estimate of the measurand (e.g. voltage) using equation (1):

$$u_c(y) = \sqrt{\sum_i c_i^{\,2} u^2(x_i)} \qquad (1)$$

U_{lab} is the expanded uncertainty defined by equation (2):

$$U_{lab} = 2u_c(y) \qquad (2)$$

Using the influence quantities defined in the standard, the values of U_{cispr} contained in Table I have been calculated based on the tolerances given in standards CISPR 16-1-x:

TABLE I
VALUES OF U_{cispr}

Measurement	Frequency range	U_{cispr}
Conducted disturbance (mains port)	9 k to 150 kHz	4,0 dB
	0,15 to 30 MHz	3,6 dB
Disturbance power	30 to 300 MHz	4,5 dB
Radiated disturbance on OATS or SAC	30 to 1000 MHz	5,2 dB

The following rules apply depending on U_{lab}:

If $U_{lab} \leq U_{cispr}$ then compliance occurs, if no measured disturbance exceeds the limit.

If $U_{lab} > U_{cispr}$ then compliance occurs, if no measured disturbance increased by $U_{lab} - U_{cispr}$ exceeds the limit.

D. Influence of Amendments to Basic Standards

After CISPR 16-4-2 had been published, the existing parts CISPR 16-1-x were amended, which will be taken into account in the revision. In conducted disturbance measurements

(mains port), the strongest influence quantity is the deviation of the AMN impedance from the reference value. Originally, CISPR 16-1-2 specified only the impedance magnitude with a tolerance of 20 %. In CISPR 16-4-2 a tolerance circle for the impedance was assumed (see Fig. 1), which includes an upper bound for the impedance phase.
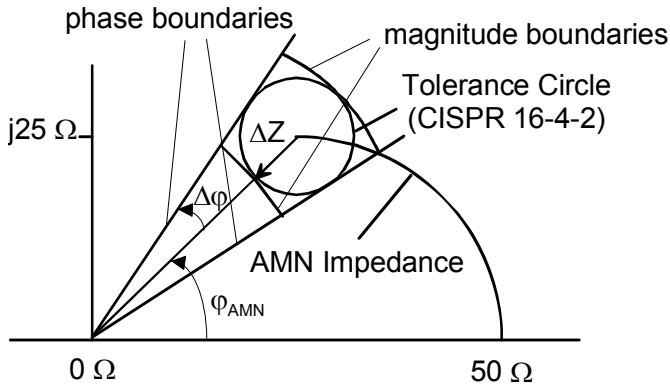

Fig. 1 Tolerance circle for the AMN (LISN) impedance

CISPR 16-1-2 was subsequently amended by adding the tolerance of $\pm 11{,}5^{\circ}$ for the phase corresponding to the impedance magnitude tolerance. As the AMN impedance deviation has a strong impact on the total uncertainty for conducted disturbance measurements, it is vital for a test lab to be able to calculate the maximum voltage deviation due to deviation from the reference impedance given by a calibration report. The principle circuit is given in Fig. 2.
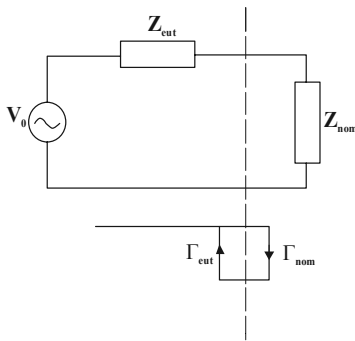

Fig. 2 EUT connected to ideal AMN and flow graph

For the real AMN, Z_{nom} is replaced by Z_{amn}. For the calculation, the reflection coefficients Γ relative to a normalizing impedance Z_0 (e.g. 50 Ω) are used:

$$\Gamma_{nom} = \frac{Z_{nom} - Z_0}{Z_{nom} + Z_0}, \ \Gamma_{eut} = \frac{Z_{eut} - Z_0}{Z_{eut} + Z_0} \ \text{and} \ \Gamma_{amn} = \frac{Z_{amn} - Z_0}{Z_{amn} + Z_0}$$

$$V_{nom} = \frac{Z_{nom}}{Z_{eut} + Z_{nom}} V_0 = \frac{(1 + \Gamma_{nom})(1 - \Gamma_{eut})}{2(1 - \Gamma_{nom}\Gamma_{eut})} V_0$$

$$V_{amn} = \frac{Z_{amn}}{Z_{eut} + Z_{amn}} V_0 = \frac{(1 + \Gamma_{amn})(1 - \Gamma_{eut})}{2(1 - \Gamma_{amn}\Gamma_{eut})} V_0$$

As Z_{amn} is allowed to deviate from Z_{nom}, V_{amn} will deviate from V_{nom}. The relative deviation may be calculated using (3).

$$\left| \frac{V_{amn}}{V_{nom}} \right| = \left| \frac{1 + \Gamma_{amn}}{1 - \Gamma_{eut}\Gamma_{amn}} \cdot \frac{1 - \Gamma_{eut}\Gamma_{nom}}{1 + \Gamma_{nom}} \right| \qquad (3)$$

As explained above (see tolerance circle in Fig. 1),

$$Z_{amn} = Z_{nom} + \alpha |Z_{nom}| \exp(j\theta) \ \text{with} \ 0 \le \alpha \le 0{,}2 \ \ 0 \le \theta < 2\pi$$

The value of Z_{eut} is unknown and unbounded, however the magnitude of Γ_{eut} cannot be greater than unity, allowing Γ_{eut} to be written as:

$$\Gamma_{eut} = \rho \exp(j\phi) \ \text{with} \ 0 \le \rho \le 1 \ \text{and} \ 0 \le \phi \le 2\pi$$

Physical considerations suggest that the extremes of (3) are likely to be found when $\alpha = 0{,}2$ and $\rho = 1$. In this case, using all possible combinations of θ and φ, the extreme values of 2,68 dB and – 2,6 dB will be found for (3) at 150 kHz for the 50 μH//50 Ω AMN. At other frequencies, the voltage deviations are smaller. Using a computer program for (3), the extremes can be found for given values of the AMN impedance.

In disturbance power measurements, apart from the uncertainty of the clamp factor itself, a strong influence is caused by the environment, i.e. the absorbing clamp test site. In order to limit this effect, a validation method has been added to CISPR 16-1-3, where the clamp factor measured in situ is compared to the clamp factor measured on a reference site. The validation setup is shown in Fig. 3:
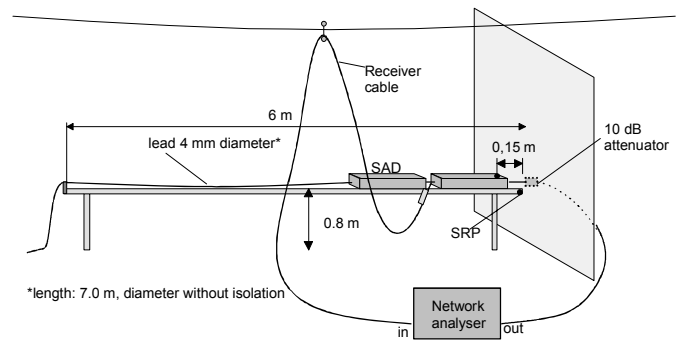

Fig. 3 Setup of absorbing clamp test site validation

The maximum difference between the two clamp factors is +/-2,5 dB in the frequency range from 30 to 300 MHz.

In radiated disturbance measurements on the open area test site/semi-anechoic chamber (OATS/SAC), the antenna factor height dependence in the frequency range below 300 MHz was treated as the difference between the height dependences of the reference antenna and the actual measuring antenna. Between 80 and 300 MHz, the reference antenna was the balanced resonant dipole, i.e. the half-wave dipole. After a debate of the adequacy, the reference antenna was replaced by the electric field strength as the reference in CISPR 16-1-4. This causes a revision of the influence quantity antenna factor height dependence.

Further, in radiated disturbance measurements, the shape, construction and material permittivity of an EUT turntable can influence field-strength measurement results. Consequently it

has to be regarded as an influence quantity. For an estimate of the amount of uncertainty, the evaluation procedure for setup table influences described in CISPR 16-1-4 must be used. The procedure uses a comparison of the output voltage of a broadband dipole antenna with and without the setup table.

III. EXTENSION OF CISPR 16-4-2

A. Measurement methods to be added

Whereas the basic rules will be kept, the structure and contents will be amended to include more measurement methods.

For conducted disturbance measurements in the frequency range up to 30 MHz on the EUT power and telecommunication ports, the following is planned to be added:
- measurements using a voltage probe on the power port
For conducted disturbance on the telecommunication port:
- measurements using a current probe,
- measurements using the capacitive voltage probe (CVP)
- measurements using an asymmetric artificial network (AAN) – which is the specific term for "impedance stabilization network (ISN)" on the telecommunication port.
For radiated disturbance measurements in the frequency range 30 to 1000 MHz, the inclusion of:
- fully anechoic room (FAR) measurements is planned.
In addition, the draft includes:
- radiated disturbance measurements from 1 to 18 GHz.
A first committee draft [4] has already been commented by the national committees.

B. Uncertainties for conducted disturbance measurements

The AMN impedance tolerance is a large source of uncertainty. The impedance tolerance for current and voltage probes is comparatively small, which results in a smaller value of U_{cispr} (2,9 dB compared to 3.6 dB for the AMN and between 3,9 and 4,8 dB for the AAN depending on LCL). This should however not cause any standards writer to replace the AMN or the AAN by a current or voltage probe, as there is no decoupling between the EUT port and the mains port respectively the AE port of the current or voltage probe. No decoupling means that the measurement result is largely determined by the mains impedance respectively by the auxiliary equipment (AE) impedance. Compared to measurements using the AMN or the AAN, the estimated compliance uncertainty may rise by a factor of 6.

For disturbance measurements on telecommunication ports using the AAN, one source of uncertainty is the asymmetric AAN impedance tolerance – which affects the measurement of the launched common mode disturbance of the EUT. Another source of uncertainty is the longitudinal conversion loss (LCL) tolerance of the AAN – which affects the measurement of the converted common mode disturbance of the EUT. The LCL tolerance is depending on the frequency range and on the specified LCL value. It is ± 3 dB for an LCL value of 55 dB at 150 kHz falling to 40 dB at 30 MHz (for CAT3) and it is + 6/- 3 dB for an LCL value of 75 dB at 150 kHz falling to 60 dB at 30 MHz (for CAT6). Both influence quantities are independent of each other: the amount of launched common mode dis-

turbance of an EUT cannot be predicted and the amount of converted common mode disturbance depends on the amplitude of the differential mode signal and the LCL value of the AAN. An equation equivalent to eq. (3) will be used to calculate the maximum voltage deviation due to the impedance deviation to find $u(x_{imp})$. The deviation from the specified LCL value directly results in a voltage deviation of the same amount to find $u(x_{lcl})$. Hence, assuming triangular probability distribution equation (1) applies with $u(x_{imp}) = 0,47$ dB and $u(x_{lcl}) = 1,22$ dB for CAT3 and $u(x_{lcl}) = 1,84$ dB for CAT6 telecommunication cables.

C. Uncertainties for radiated disturbances at 3 m distance

To measure the true field strength of an EUT above a reflecting ground plane in the frequency range below 1 GHz, CISPR 16-1-4 requires the responses of a complex antenna in the direction of the direct ray and in the direction of the ground-reflected ray to be within 1 dB. To meet this requirement at 3 m distance, the boresight of the antenna may have to be tilted downwards, or, if tilting is not employed, the reduction in received signal may need to be corrected. Most antenna towers do not allow antenna tilting. This antenna directivity problem exists despite the fact that measurements at 3 m distance are not normative in CISPR product standards 11 and 22 and despite the fact that system sensitivity – for which high antenna gain is an advantage – is not a problem at 3 m distance. Fig. 4 shows a setup with an LPDA in vertical polarization without tilting.
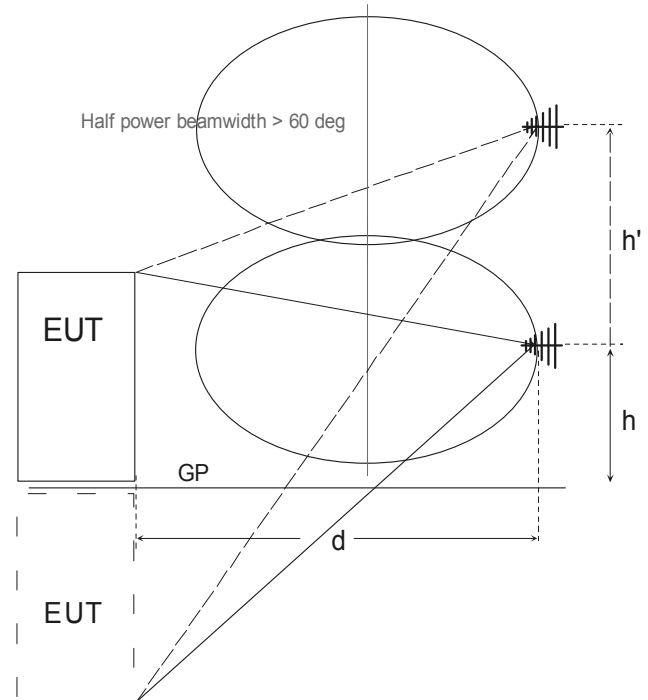

Fig. 4 Effect of antenna directivity without tilting

The drawing in Fig. 4 shows that the correction factor is an estimate of the inverse of the average reduction of measured voltage caused by the antenna directivity pattern taking the antenna height variation into account. The phase center loca-

tion of EUT radiation is unknown, so the antenna height of maximum field strength is not calculable. [5] assumes equal probability distribution of the EUT radiation phase center location along the EUT height. Thus it is possible to calculate the probability distribution of the reduction and the correction factor. Since the correction is obtained from the slope of the directivity pattern, a large amount of uncertainty is associated with the correction factor. In order to minimize the uncertainty, the correction factor could be calculated for the antenna height of maximum output voltage. A lower uncertainty would be obtained with tilting as shown in Fig. 5.
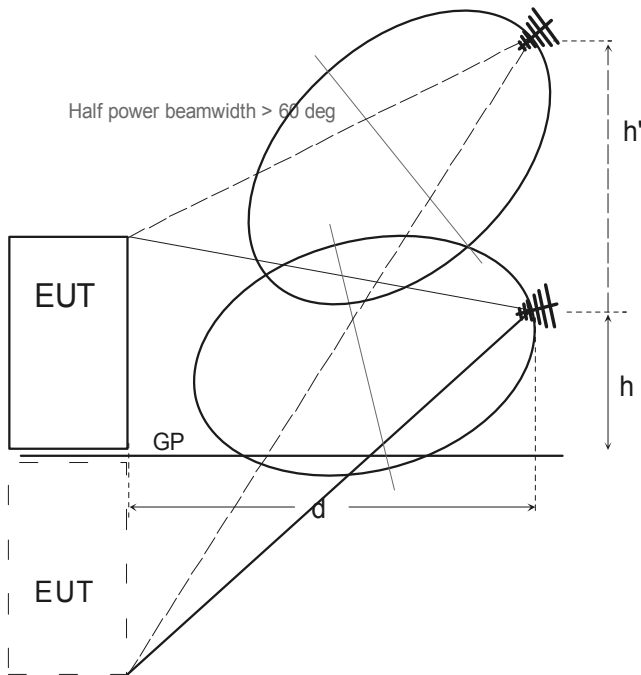

Fig. 5 Effect of antenna directivity with tilting

As can be seen from Fig. 5, the lowest uncertainty would be obtained with height-dependent tilting angles, so that both, direct and reflected rays are equally received, which is mechanically complicated. An improvement compared to non-tilting would also be achieved using the average of the height-dependent tilting angle as a fixed tilting angle.

In addition to the antenna directivity problem, there is a near-field problem with measurements at 3 m distance on the OATS/SAC especially at frequencies above 500 MHz. The measurand for radiated disturbance measurements in product standards CISPR 11 and 22 is defined for 10 m distance. Due to the mirror effect of the ground plane, the EUT height appears doubled which increases the near-field effect by a factor of 4. Any estimate of the near-field uncertainty is depending on the actual EUT size.

D. Uncertainties for Radiated Disturbances in a FAR

Uncertainties due to antenna directivity and near-field effects are much smaller, if EUTs are measured in a FAR than on the OATS/SAC at 3 m distance. No antenna tilting is required. Also there is no antenna factor height dependence – only a small effect of the FAR on the antenna factor. Hence

the FAR has not only major advantages over the OATS/SAC in that it allows low-cost test chambers – it also causes lower uncertainties. The largest source of uncertainty are the site imperfections, where validation criterion amounts to ± 4 dB. In addition, the FAR allows both emission and immunity testing with a unified EUT arrangement.

E. Uncertainties for Radiated Disturbances above 1 GHz

The measurand for radiated disturbances above 1 GHz is the field strength at the reference distance of 3 m. This solves the near-field problem for this distance. If an alternative distance is used, then the uncertainty due to near-field effects has to be investigated.

Common to all radiated disturbance test methods, the major influence factor on measurement instrumentation uncertainty is due to site imperfections. The validation method for the FAR above 1 GHz applies a site voltage standing wave ratio (Svswr) test method with a site acceptability criterion of 6 dB. There was debate about the method to derive an estimate of the uncertainty from the maximum Svswr of 6 dB. It was proposed to assume ± 3 dB with U-distribution. The divisor for U-distribution is √2, which results in 2,12 dB, which is a rather large value.

The author proposes a more reliable procedure based on the working group document [6]. This document shows that a Svswr of 6 dB approximately corresponds with a deviation of 4 dB from the ideal normalized site attenuation. The deviation from normalized site attenuation gives a good estimate of the uncertainty of field strength measurement. An upper bound of 4 dB means that the coverage factor k is more than 3. Assuming k = 3, gives a value of 1,33 for the standard uncertainty.

Other special uncertainty contributions for measurements above 1 GHz include the effect of antenna directivity and the effect of external preamplifier gain variations and mismatch.

IV. Conclusion

The amendment of CISPR 16-4-2 includes the revision of existing material and the addition of new material for 6 further test methods, 4 conducted and 2 radiated tests. Due to space limitations, only an extract of the many details of the amendment was given. However the importance of the definition of the measurands was emphasized. A clear definition of the measurand helps to avoid misunderstandings and shows the effect of deviations from the intended test method.

References

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