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TECHNICAL REPORT

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INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

AMENDMENT 2

Specification for radio disturbance and immunity measuring apparatus and methods –
Part 4-5: Uncertainties, statistics and limit modelling – Conditions for the use of alternative test methods

CISPR TR 16-4-5:2006-10/AMD2:2021-10(en)

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Specification for radio disturbance and immunity measuring apparatus and methods –
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FOREWORD

This amendment has been prepared by subcommittee CISPR A: Radio-interference measurements and statistical methods, of IEC technical committee CISPR: International special committee on radio interference.

The text of this amendment is based on the following documents:

DTR	Report on voting
CIS/A/1321/DTR	CIS/A/1324/RVDTR

Full information on the voting for the approval of this amendment can be found in the report on voting indicated in the above table.

The committee has decided that the contents of this amendment and the base publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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1 Scope

Add, in the second sentence, the following new text "and total radiated power" *to the parentheses to read:* "i.e. field strength and total radiated power".

2 Normative references

Add the following new reference to the existing list:

CISPR 16-1-1:2019, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*

Delete the existing reference to CISPR 16-4-1, modified by Amendment 1.

Replace the existing reference to CISPR 16-4-2:2003 with the following:

CISPR 16-4-2:2011, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Measurement instrumentation uncertainty*
CISPR 16-4-2:2011/AMD1:2014
CISPR 16-4-2:2011/AMD2:2018

3 Terms and definitions

3.8
intrinsic uncertainty of the measurand

Replace the existing source, modified by Amendment 1, with the following: "[CISPR 16-4-1:2009, 3.1.6, modified – Deletion of notes]"

Add, after the existing definition 3.10, added by Amendment 1, the following new term and definition as follows:

3.11
EUT volume
cylinder defined by EUT boundary diameter and height that fully encompasses all portions of the actual EUT, including cable racks and 1,6 m of cable length (for 30 MHz to 1 GHz), or 0,3 m of cable length (for 1 GHz and above)

NOTE 1 The test volume is one of several criteria limiting the EUT volume.

NOTE 2 The EUT volume has a diameter *D* (boundary diameter) and a height *h*.

4 Symbols and abbreviated terms

Add, to the existing introductory statement, the following new sentence as follows:

The following abbreviations are used in this technical report. Note that the symbol *k* is used for four different quantities.

Add the following new lines to the existing list modified by Amendment 1:

FAR fully anechoic room

RC reverberation chamber

SCU standards compliance uncertainty

Replace the two existing lines K and k with the following:

k $= 2\pi/\lambda$, wave number (in this document, k is used in the electrical size ka, where a is the EUT radius)

$k(f)$ linear conversion factor

$K(f)$ logarithmic conversion factor

k coverage factor

k Boltzmann's constant

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5 Introduction

Replace the existing text with the following new text:

Over the years, several test methods and test set-ups for radiated disturbance measurement have been described in basic standards. One particular combination of test method and test set-up also having defined disturbance limits is the open area test site (OATS) method, which has proven to be successful for the protection of radio services. Since the first edition of this document, limits have been defined for other – alternative – test methods, e.g., fully anechoic rooms and TEM waveguides, but not for reverberation chambers.

Each alternative method can be used to get measurement results related to disturbance from an EUT. Although each method gives a disturbance level from an EUT, the different methods might capture the EUT disturbance differently. For example, considering radiated disturbance measurements, different methods may capture different EUT radiation pattern lobes, a different number of lobes, or the test facility might alter the EUT radiation pattern producing a different apparent disturbance level. Therefore the limits defined for the established test method cannot be applied directly to the alternative test methods. Consequently, procedures are needed to derive limits to be used for the results of alternative test methods.

The specification of such procedures considers the general goal of disturbance measurements, which is to verify whether an EUT satisfies or violates certain compliance criteria. Past experience has shown that using the present system of established test methods and associated limits yields a situation without many cases of interference due to conducted disturbance or radiated disturbance. Applying an established test method with its associated limits will fulfill the protection requirement with a high probability. To preserve this situation, the most important requirement for the use of alternative test methods is the following:

– Use of an alternative test method in a normative standard shall provide the same protection of radio services as the established test method.

This requirement can be met by developing procedures to derive disturbance limits for alternative test methods from the existing limits of the established test methods. Such procedures shall relate the results from an alternative test method to those from an established test method. Using the relations derived in this document, the limits of the relevant established test method can be converted into limits for the alternative test method. The measured values of the alternative test method can then easily be evaluated against the converted limits. Such procedures will provide a similar amount of protection, even though an alternative test method is used.

The limit conversion procedures consider the preceding goal of disturbance measurements. The results of standard disturbance measurements can be considered as an approximation of the interference potential of an EUT. Depending on the characteristics of an EUT (e.g., radiation pattern characteristics for radiated disturbance test methods), and the test set-up, the measured value deviates from the actual interference potential of the EUT. This deviation can be divided into two parts: 1) a systematic deviation, which can be interpreted as a bias of the test method; and 2) a random deviation depending on the characteristics of different EUTs, which can be interpreted as an uncertainty of the test method. Each disturbance test method contains both quantities, and consequently the established test method does too. In the following clauses, a procedure based on these two quantities for comparing an alternative test method with the established test method is described. To determine these quantities, the abstract term “interference potential” shall be expressed in terms of a physical quantity. For the purposes of this document, this physical quantity is called the “reference quantity” X. Other details about comparison of test methods using a reference quantity can be found in [1][1].

[1] Figures in square brackets refer to the Bibliography.

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The significance of a reference quantity is under discussion (see Magdowski [16]). It is not used in the derivation of limits for an alternative test method based on measurements (see Clause 7 of CISPR TR 16-4-5:2006/AMD1:2014), and in the derivation of limits for disturbance measurements using a reverberation chamber (i.e. in this document).

Figure 1 – Overview of quantities to estimate for use in conversion procedure

Replace the existing figure with the following:

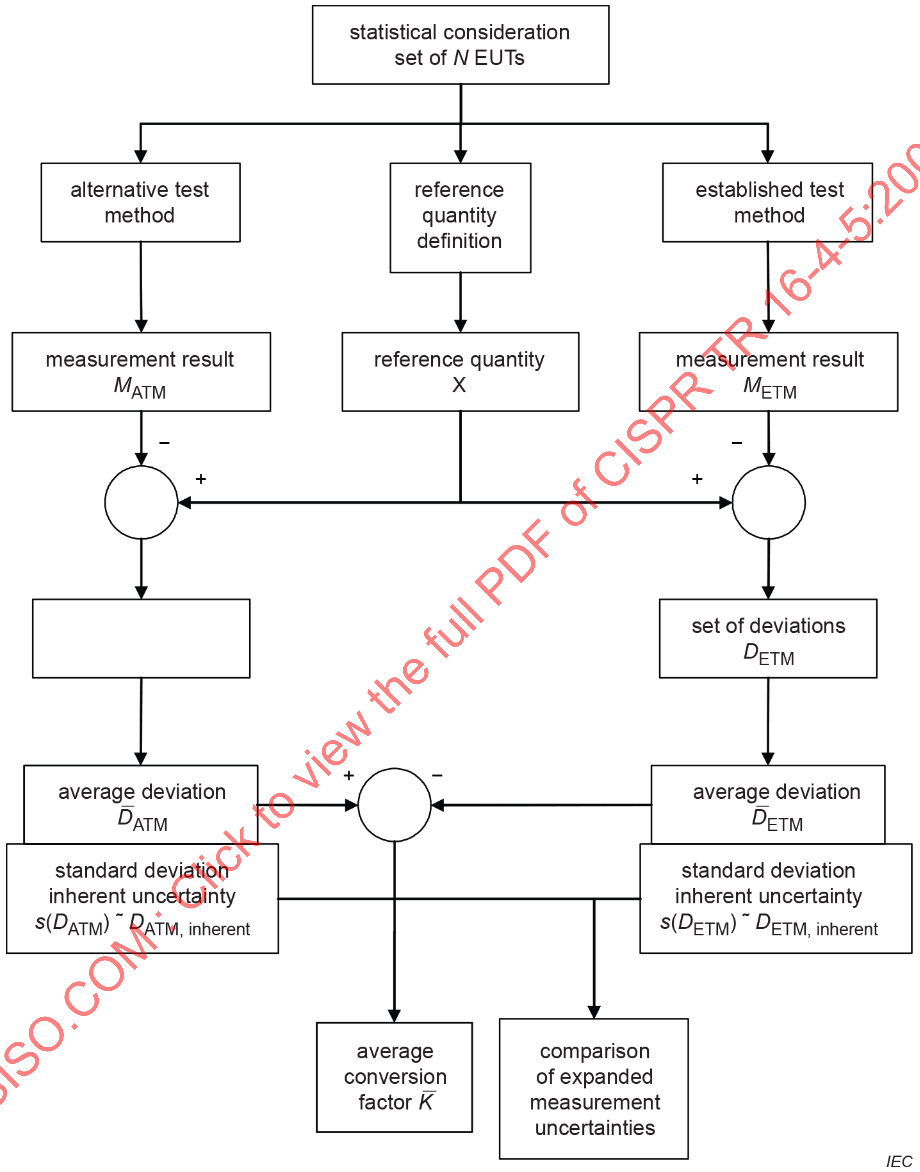

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Figure 2 – Overview of limit conversion procedure using estimated quantities

Replace the existing figure with the following:

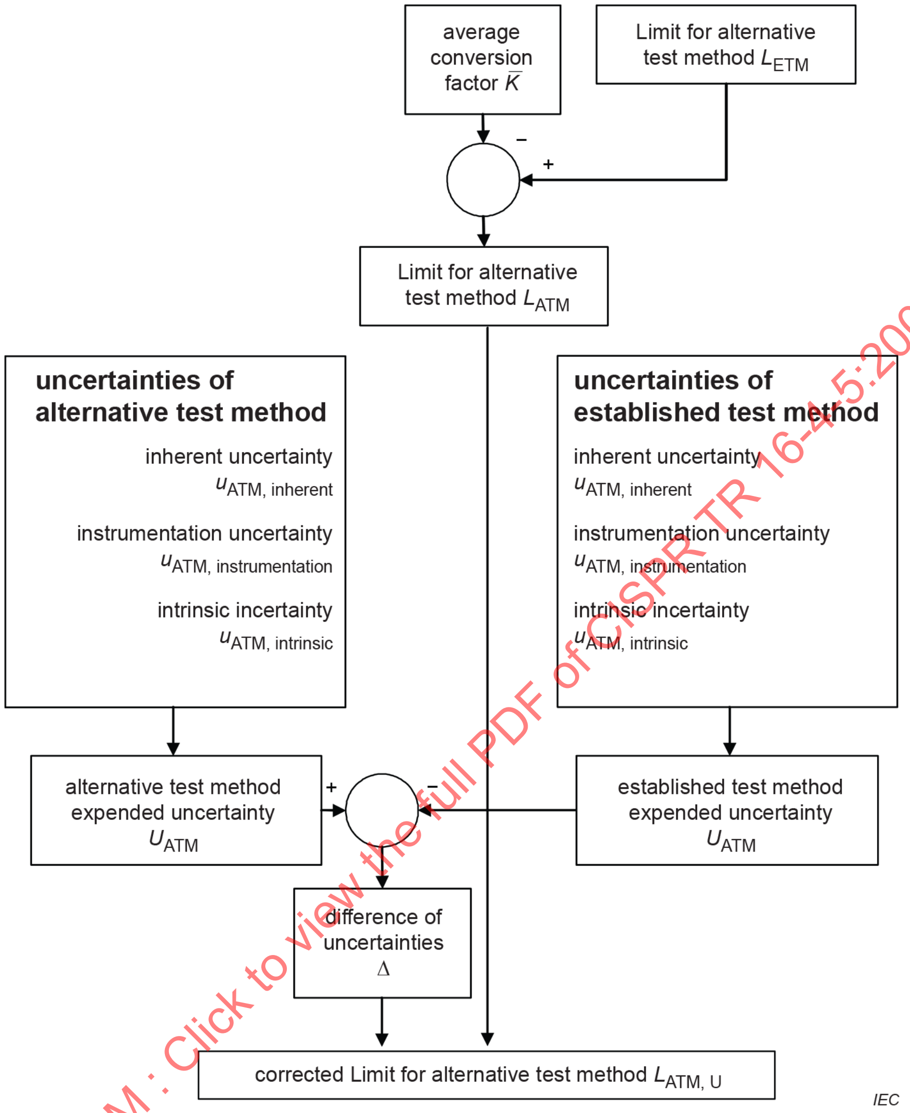

Table 2 – Overview of quantities and defining equations for conversion process

Add, at the bottom of the existing table, modified by Amendment 1, the following new rows:

E_{max}	Maximum field strength of an EUT in µV/m measured using the ETM, i.e. at d = 10 m at an OATS/SAC from 80 MHz to 1 000 MHz, and at d = 3 m at a FSOATS/FAR from 1 GHz to 18 GHz	(35)
P_T	Power transmitted from an EUT in pW measured using the reverberation chamber test method (ATM), and virtual power[a)] producing the field-strength maximum E_{max} measured using the ETM	(35)
[a)] The virtual power is the power generating E_{max} assuming the EUT directivity is estimated in this document.		

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Add, after the existing Clause 7, modified by Amendment 1, the following new Clause 8:

8 Derivation of limits for the use of reverberation chambers as ATM for radiated disturbance measurements based on a statistical analysis of all essential factors

8.1 Conversion factor

Measurement of radiated power from an EUT using the RC method is described in IEC 61000-4-21 [22]. This clause attempts to provide rules to derive disturbance limits for the radiated power measured using the RC test method based on existing limits for radiated field strength measured using the ETM. Radiated field strength and radiated power of an EUT are related via the EUT directivity, and EUT directivity depends on frequency and EUT volume. Because the type of an EUT and its directivity are typically unknown for generic and product standards, this clause uses a statistical estimate based on assumptions described by Krauthäuser [19]. For comparison and easier understanding, the conversion factors using a short dipole as a model are described in D.2.

With reference to Annex D, conversion factors

– from OATS/SAC to RC for 80 MHz to 1 000 MHz, and

– from FSOATS/FAR to RC for 1 GHz to 40 GHz.

are introduced.

NOTE The start frequency of 80 MHz is selected because IEC 61000-4-21:2011, Table B.2 [22] on field uniformity requirements starts at 80 MHz. Because there are RCs with lower or higher lowest useable frequencies (LUFs), 80 MHz can be replaced by "LUF." The highest frequency of 40 GHz is selected because that is under consideration to be the highest frequency for all CISPR documents pending agreement by NCs.

The linear conversion factor $k(f)$ is defined as in Equation (35)

$$k(f) = E_{\max}^2 / P_T \tag{35}$$

where

$E_{\max}$ is the maximum field strength of an EUT in µV/m measured using the ETM;

P_T is the power transmitted from an EUT in pW measured using the RC test method.

The unit of $k(f)$ is V^2/m^{2}W or Ω/m^2. To convert into logarithmic quantities, Equation (35) can be written as Equation (36):

$$\begin{aligned} \lg P_T &= \lg E_{\max}^2 - \lg k(f), \text{ or} \\ 10\lg P_T &= 20\lg E_{\max} - 10\lg k(f) \end{aligned} \tag{36}$$

The logarithmic conversion factor $K(f)$ is defined as in Equation (37):

$$K(f) = 10\lg k(f) \tag{37}$$

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The logarithmic conversion factor can be used to convert radiated disturbance limits L_{ETM} in dB(µV/m) into limits of the disturbance power L_{ATM} in dB(pW) measured in an RC as shown in Equation (38) (see also Equation (15) in 6.10).

$$L_{\text{ATM}}/\text{dB}(\text{pW}) = L_{\text{ETM}}/\text{dB}(\mu\text{V/m}) - K(f) \quad (38)$$

The logarithmic conversion factor $K(f)$ has the unit dB(Ω/m^2).

8.2 Measurement uncertainty

Equation (7) and Equation (9) of 6.7 provide the combined standard uncertainties of ATM and ETM results with contributions designated in subscripts as: "m" for the instrumentation uncertainty, "intrinsic" for the intrinsic uncertainty of the measurand, and "inherent" for the inherent uncertainty of the method.

$$u_{\text{XTM}} = \sqrt{u_{\text{XTM,m}}^2 + u_{\text{XTM,intrinsic}}^2 + u_{\text{XTM,inherent}}^2}$$

where X in the subscript terms denotes either E or A (i.e. ETM or ATM).

For the effect of the measurement uncertainties of ETM and ATM on the disturbance limit, the expanded uncertainties are compared (see Equation (16) in 6.10). The expanded uncertainty of the conversion factor in Annex D (2σ in Table D.2, Table D.3,Table D.4,Table D.6, Table D.7 and Table D.8) takes into account the inherent uncertainties of the ETM ($U_{\text{inherent,ETM}}$) and ATM ($U_{\text{inherent,ATM}}$). The inherent uncertainty is an indicator of the ability of a measurement procedure to account for differences in EUT characteristics. A three-dimensional (3D) spatial scan would provide the lowest uncertainty for capturing the maximum field strength radiated by an EUT, but none of the ETMs are ideal in that respect. However, the RC ATM does capture the radiated power of an EUT across all directions. Consequently, the inherent uncertainty of the RC ATM is zero whereas the inherent uncertainties of the ETMs are non-zero.

In addition to the uncertainty of the conversion factor, the actual EUT size can deviate from the EUT size assumed for the conversion factor calculation in Annex D, which justifies a contribution U_{EUT}.

As can be seen from Table H.1 of CISPR TR 16-4-1:2009, the SCU $U_{\text{ETM,SC}}$ of the ETM (OATS/SAC with d = 10 m) is on the order of 10 dB, whereas $U_{\text{XTM,m}}$ is around 5 dB according to CISPR 16-4-2. Thus,

$$U_{\text{ETM,SC}} = \sqrt{U_{\text{ETM,intrinsic}}^2 + U_{\text{ETM,m}}^2}$$

and consequently

$$U_{\text{ETM,intrinsic}} = \sqrt{U_{\text{ETM,SC}}^2 - U_{\text{ETM,m}}^2} = 8{,}7\ \text{dB}$$

This means that the intrinsic uncertainty of the ETM is much larger than the uncertainty of the conversion factor K, so Equation (28) of 7.2.3 does not apply for Annex D. The intrinsic uncertainty is largely dependent on cable layout and cable termination, which is an important topic for the reproducibility of measurement set-ups. By future standardization of cable layout and cable termination, intrinsic uncertainty and standards compliance uncertainty can be minimized.

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At present values of SCU (and intrinsic uncertainty) are not available for the ETM above 1 GHz, as well as for the RC ATM below and above 1 GHz. This does not mean that the RC method should be precluded for radiated disturbance measurements usage; there is no reason to assume that the SCU of the RC method results will be larger than the SCU of the ETM results. Product committees should provide appropriate investigations and measurements for establishing the SCU.

In addition to any deviation from the EUT size for the conversion factor, the EUT type can be different from that assumed for the conversion; e.g. with different cable arrangement and cable termination. This means that Equation (32), Equation (33), and Equation (34) of 7.2.3 also apply for the use of an RC disturbance measurement method as an ATM.

Details on instrumentation contributions to uncertainty for RC disturbance measurement results is given in D.4.

B.1.1.5 Estimate the standard uncertainties of the test methods (see 6.6)

Replace the existing first paragraph with the following new paragraph:

Instrumentation uncertainty: At the time of drafting of this Annex, for the alternative test method (3 m FAR), the instrumentation uncertainty had not yet been given in CISPR standards. For the antenna and site contributions, numeric values from the final technical report of the EU FAR project have been used [4]. The other numeric values were taken from CISPR 16-4-2:2003 [24], because these were expected to be the same for OATS and FAR. These instrumentation measurement uncertainties are given in Table B.1. For the established test method, the measurement instrumentation uncertainty is as shown in the basic standard CISPR 16-4-2:2011.

B.2.1.5 Estimate the standard uncertainties of the test methods (see 6.6)

Replace, in the first paragraph, "CISPR 16-4-2:2003" with " CISPR 16-4-2:2011".

B.2.1.8 Verify the calculated values (see 6.9)

Replace, in the last paragraph, "CISPR 16-4-2:2002" with " CISPR 16-4-2:2011".

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Add, at the end of the existing Annex C, added by Amendment 1, the following new Annex D:

Annex D
(informative)

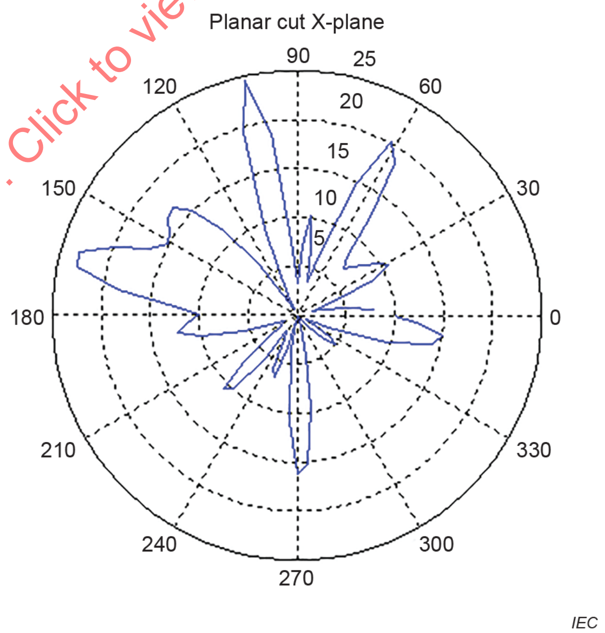
Statistical method for conversion of disturbance limits from radiated disturbance established test methods to the RC test method

D.1 General

Radiated disturbance established test methods (ETMs) measure field strength at a specified distance from an EUT, whereas the RC test method (alternative test method, ATM) measures the radiated power from an EUT. Because the EUT directivity varies from type to type, statistical techniques are used to derive conversion factors from ETM results to ATM results. With increasing electrical size of an EUT, the complexity of an EUT's radiation pattern increases (see Wilson [17]).

Wilson [17] explains how the electrical size of an EUT is established by the quantity *ka*, where $k = 2\pi/\lambda$ is the wave number, and *a* is the radius of the minimum sphere that encloses the EUT. The preceding concept applies for this entire annex. An EUT is considered electrically large, if $ka > 1$, and it is electrically small, if $ka \leq 1$. Figure D.1 shows an example radiation pattern for a simulated electrically-large emitter. Table D.1 provides the EUT dimensions for the transition from electrically small to electrically large as a function of frequency.

Wilson [17] also provides a statistical estimate of 3 dB for the probability of finding the maximum radiation between a planar-cut scan (e.g. an EUT rotation without an antenna height scan) and a full-sphere scan valid for very large EUTs. Thus, the planar-cut scan is regarded as a reduced sampling procedure for finding the maximum field strength of an EUT. This also means that the radiation limit for a full-sphere scan of a large EUT can be reduced by a conservative amount of 3 dB if the full-sphere scan is replaced by a planar-cut scan.



NOTE The Y-plane and Z-plane patterns have similar characteristics, but normally only a single lobe in one plane reaches the maximum (i.e. amplitude of 25 in this example).

Figure D.1 – Simulated radiation pattern of an electrically large emitter (50 cm radius, *ka* = 10,5 at 1 GHz) in a single plane (X-plane) (Wilson [17])

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Table D.1 – Overview of EUT diameters (= 2*a*) at the transition from electrically small to electrically large (from [17])

Frequency MHz	*k* 1/m	*ka*	radius *a* cm	diameter cm
30	0,6	1,0	159,2	318,3
100	2,1	1,0	47,8	95,5
200	4,2	1,0	23,9	47,7
500	10,5	1,0	9,6	19,1
1 000	20,9	1,0	4,8	9,6
2 000	41,9	1,0	2,4	4,8
5 000	104,7	1,0	0,9	1,9
10 000	209,4	1,0	0,5	1,0
20 000	418,9	1,0	0,2	0,5
40 000	837,8	1,0	0,1	0,2

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D.2 Models for EUT directivity

For a starting point Annex H of IEC 61000-4-20:20— [18] uses a Hertzian, i.e. short, dipole (D_{max} = 3/2, and D is directivity) as a model for an EUT. For the Hertzian dipole in free space (at an FSOATS/FAR) the linear conversion factor k can be calculated using Equation (D.1):

$$E_{max}^2 = \frac{3}{2}\frac{\eta_0}{4\pi d^2}P_T$$

$$k = \frac{E_{max}^2}{P_T} = \frac{3}{2}\frac{\eta_0}{4\pi d^2} \tag{D.1}$$

where

η_0 is the free space wave impedance (approximately 120π Ω);

d is the measurement distance.

For d = 3 m, k = 5 V²/(m²W).

For a Hertzian dipole in half space (at an OATS/SAC) a geometry factor g_{max} is included, taking into account the reflection from the ground plane, per Equation (D.2):

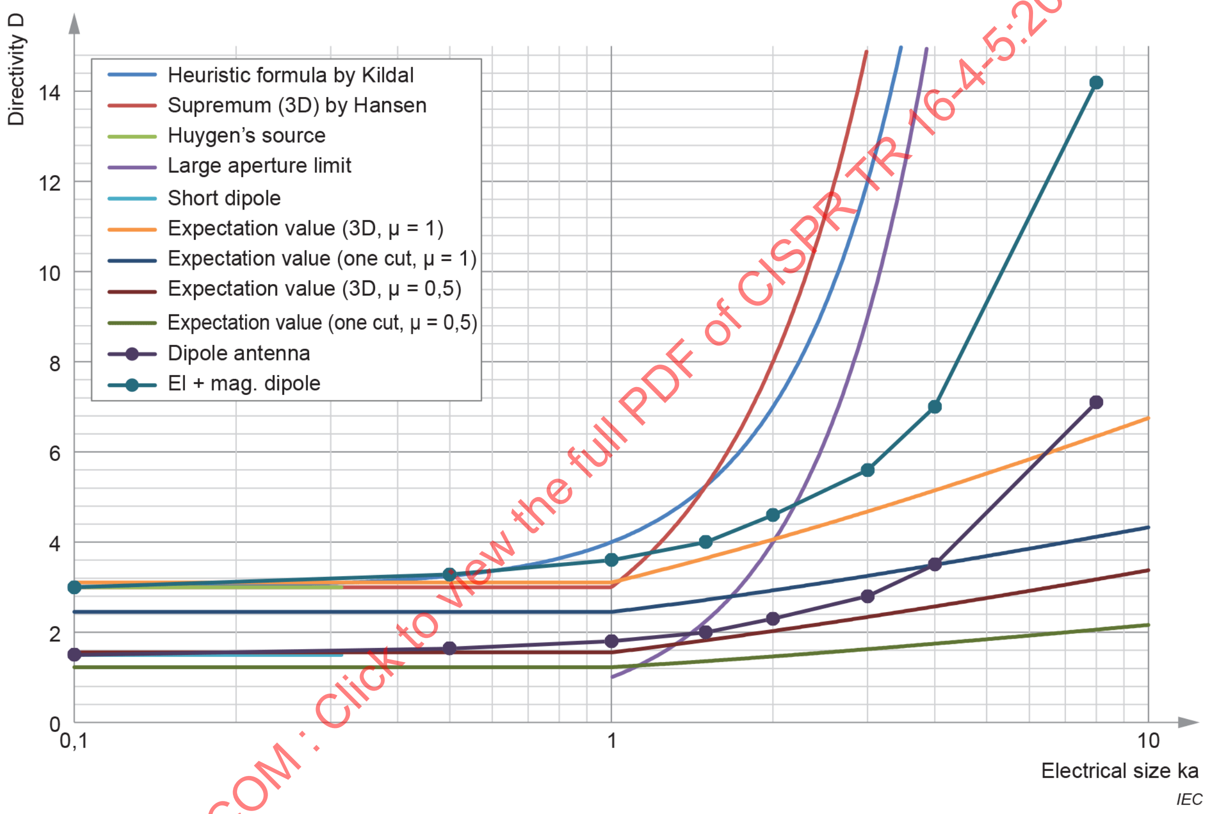
$$E_{max}^2 = \frac{3}{2}\frac{\eta_0}{4\pi d^2}g_{max}^2 P_T$$

$$k = \frac{E_{max}^2}{P_T} = \frac{3}{2}\frac{\eta_0}{4\pi d^2}g_{max}^2 \tag{D.2}$$

For d = 10 m and $g_{max} \approx 2$, k = 1,8 $V^2/(m^2W)$.

For the Hertzian dipole model, the conversion factor is independent of frequency. Using Equation (36) (see 8.1) the logarithmic conversion factor is K = 2,6 dB for the OATS/SAC to RC conversion in the frequency range 80 MHz to 1 000 MHz, and K = 7,0 dB for the FSOATS/FAR to RC conversion in the frequency range 1 GHz to 40 GHz. These conversion factors are useful for comparison with the values in D.3.

As frequency increases, the directivity increases. Krauthäuser [19] shows and compares different expressions; see Figure D.2. For modelling the directivity of unintentional radiators, Krauthäuser [19] applies two different simulations: 1) the spherical wave expansion, and 2) the Monte-Carlo method of isotropic point sources. Reference [19] establishes a link between the two methods − the two models are statistically equivalent for certain values of *ka*. A relationship for the number of sources as a function of *ka* necessary to achieve equivalent distribution functions is given. The number of angle steps to calculate the directivities of large EUTs is also described.



NOTE The two lines for "Huygen's Source" and "Short Dipole" are defined for *ka* = 0,1π only, and therefore are only visible in the lower left corner.

Figure D.2 – Comparison of different expressions for maximum directivity of antennas and unintentional emitters as a function of electrical size *ka*. μ is the polarization mismatch factor

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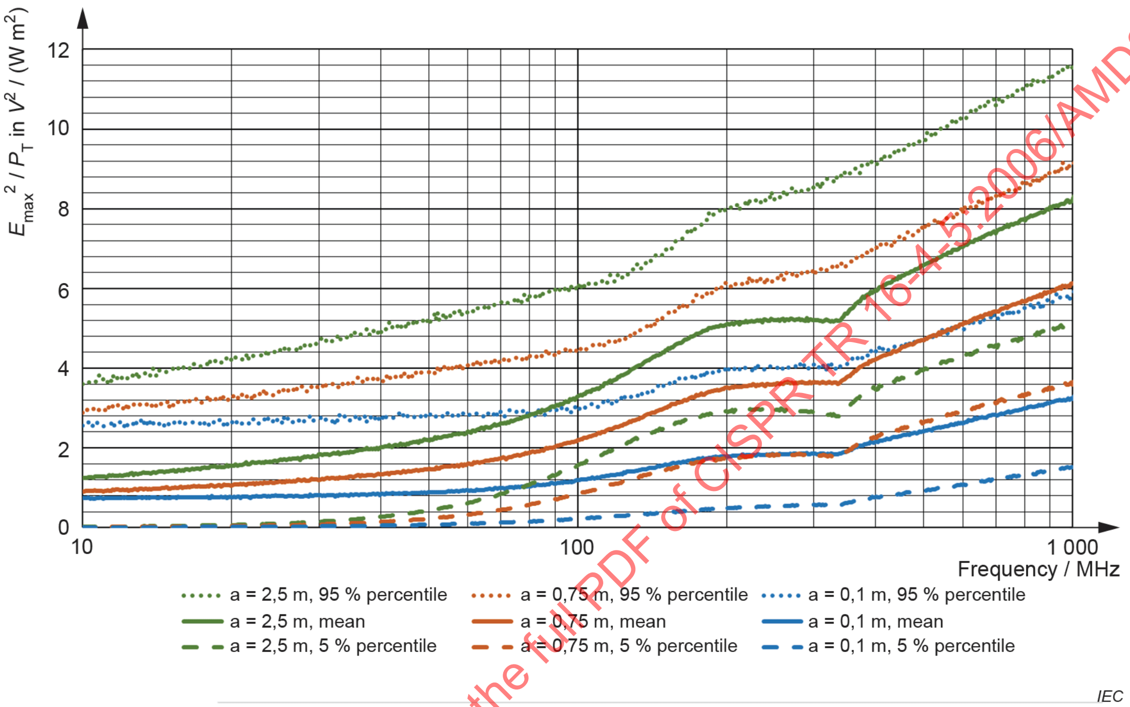
D.3 Results of modelling

Krauthäuser [19] provides conversion factors as a function of frequency and EUT size from OATS/SAC to RC, as shown in Figure D.3.

Conversion factors $k(f)$ of Table D.2, Table D.3 and Table D.4 are taken from the 'mean' curves. To convert field-strength limits to limits of the transmitted power, values in dB are more practical [$K(f) = 10\lg k(f)$]. Consequently, $P_{limit} = E_{limit} - K(f)$ [see Equation (15) in 6.10, and Equation (35) and Equation (38) in 8.1]. If conversion factors for other EUT radii are to be determined, interpolation should be done between the mean-value curves of Figure D.3.

Table D.5 shows an example of limits for *E* and *P* for *a* = 0,75 m for the residential environment.

The values for the standard deviations σ in the tables are obtained by dividing the difference between the mean and the quantile values of *K*(*f*) by 1,645, assuming a normal distribution (the factor applies for 5 %, 95 %); e.g. $\sigma = (K(230)_{95\,\%} - K(230)_{\text{mean}})/1{,}645$ = 1,34 dB for *a* = 0,75 m at 230 MHz. The variable σ is the standard uncertainty of the conversion factor. In the diagrams of [19], σ increases when *k*(*f*) approaches 0.



NOTE Data for *a* = 0,1 m, 0,75 m and 2,5 m directivities (instead of 100 as in [19]) were provided by Dr. Magdowski using Krauthäuser's material.

Figure D.3 – Conversion factors (mean and quantile values) from OATS/SAC (measurement distance of 10 m) results to RC results and different radii *a* of the surrounding sphere as a function of frequency

Table D.2 – Conversion factors (mean, quantile values, and standard deviation *σ*) for *a* = 0,1 m

f MHz	80			230			1 000		
Quantile	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB
95 %	2,81	4,49	2,71	4,31	6,34	2,23	5,78	7,62	1,55
Mean	1,05	**0,21**		1,82	**2,60**		3,23	**5,09**	
5 %	0,158	−8,0	4,89	0,532	−2,74	3,29	1,47	1,67	2,07

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Table D.3 – Conversion factors (mean, quantile values, and standard deviation *σ*) for *a* = 0,75 m

f MHz	**80**			**230**			**1 000**		
Quantile	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB
95 %	4,31	6,34	2,1	5,86	7,68	1,34	8,93	9,51	1,03
Mean	1,88	**2,74**		3,57	**5,53**		6,12	**7,87**	
5 %	0,62	−2,1	3,03	1,87	2,72	1,67	3,64	5,61	1,34

Table D.4 – Conversion factors (mean, quantile values, and standard deviation *σ*) for *a* = 2,5 m

f MHz	**80**			**230**			**1 000**		
Quantile	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB
95 %	5,84	7,66	1,92	8,39	9,23	1,24	11,43	10,58	1,3
mean	2,82	**4,50**		5,18	**7,14**		8,22	**9,15**	
5 %	1,10	0,41	2,48	3,0	4,77	1,47	5,00	6,99	0,88

Table D.5 – Example of disturbance limits for *a* = 0,75 m (EUT diameter 1,5 m) for the residential environment

f MHz	**80**	**230**	**230**	**1 000**
E_{limit} dB(μV/m)	30	30	37	37
K(*f*) dB(Ω/m²)	2,74	5,53	5,53	7,87
P_{limit} dB(pW)	27	24	31	29
P_{limit} dBm	−63	−66	−59	−61

Above 1 GHz, the ETM is measurement at an FSOATS/FAR with *d* = 3 m. Figure D.4 shows the results of modelling.

The conversion factors of Table D.6, Table D.7, and Table D.8 for frequencies of 1 GHz, 3 GHz, and 6 GHz are taken from the mean values in Figure D.4 with *a* = 0,75 m.

Table D.9 shows an example of limits for *E* and *P* for *a* = 0,75 m for the residential environment.

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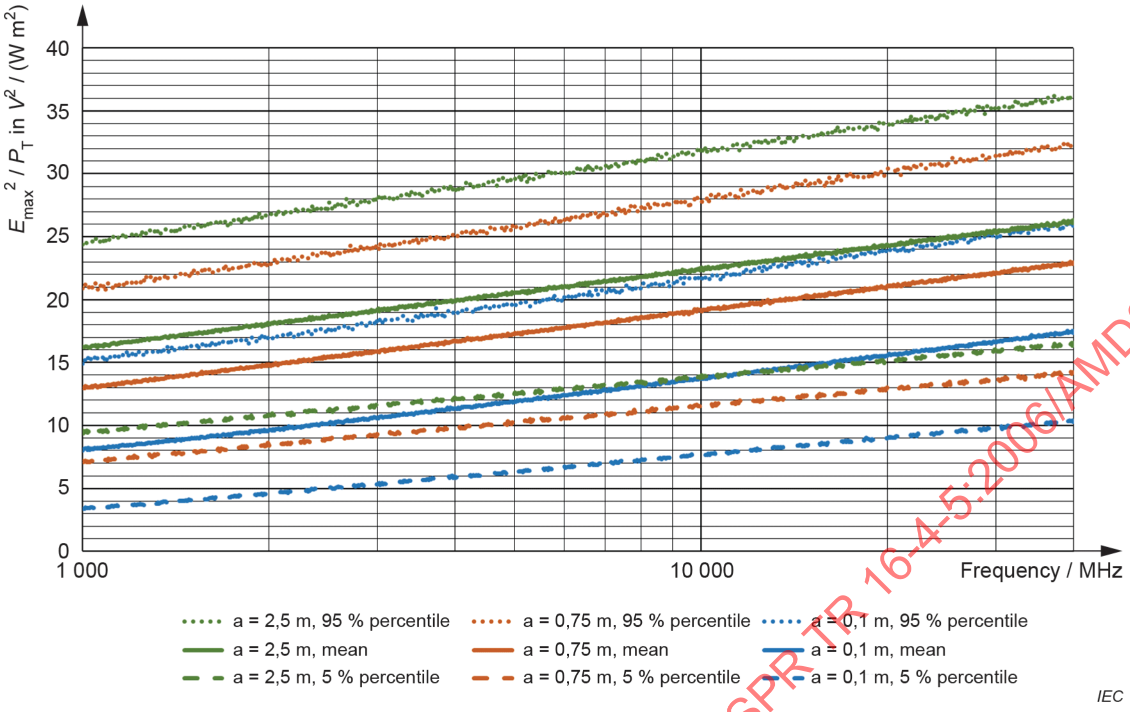

NOTE Data for *a* = 0,75 m and 2,5 m, and 1 000 directivities (instead of 100 as in [19]) were provided by Dr. Magdowski using Krauthäuser's material.

Figure D.4 – Conversion factors (mean and quantile values) from FSOATS/FAR (*d* = 3 m measurement distance) results to RC results and different radii *a* of the surrounding sphere as a function of frequency

Table D.6 – Conversion factors (mean, quantile values, and standard deviation *σ*) for *a* = 0,1 m

f GHz	**1**			**3**			**6**		
Quantile	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB
95 %	14,80	11,70	1,59	18,54	12,68	1,43	20,02	13,01	1,28
mean	7,97	**9,01**		10,70	**10,29**		12,8	**11,07**	
5 %	3,22	5,08	2,43	5,29	7,23	1,88	6,74	8,29	1,59

Table D.7 – Conversion factors (mean, quantile values, and standard deviation *σ*) for *a* = 0,75 m

f GHz	**1**			**3**			**6**		
Quantile	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	*σ* dB
95 %	21,0	13,22	1,25	24,65	13,92	1,19	26,52	14,24	1,06
Mean	13,0	**11,14**		15,8	**11,98**		17,8	**12,50**	
5 %	7,33	8,65	1,53	9,13	9,6	1,43	10,23	10,1	1,45

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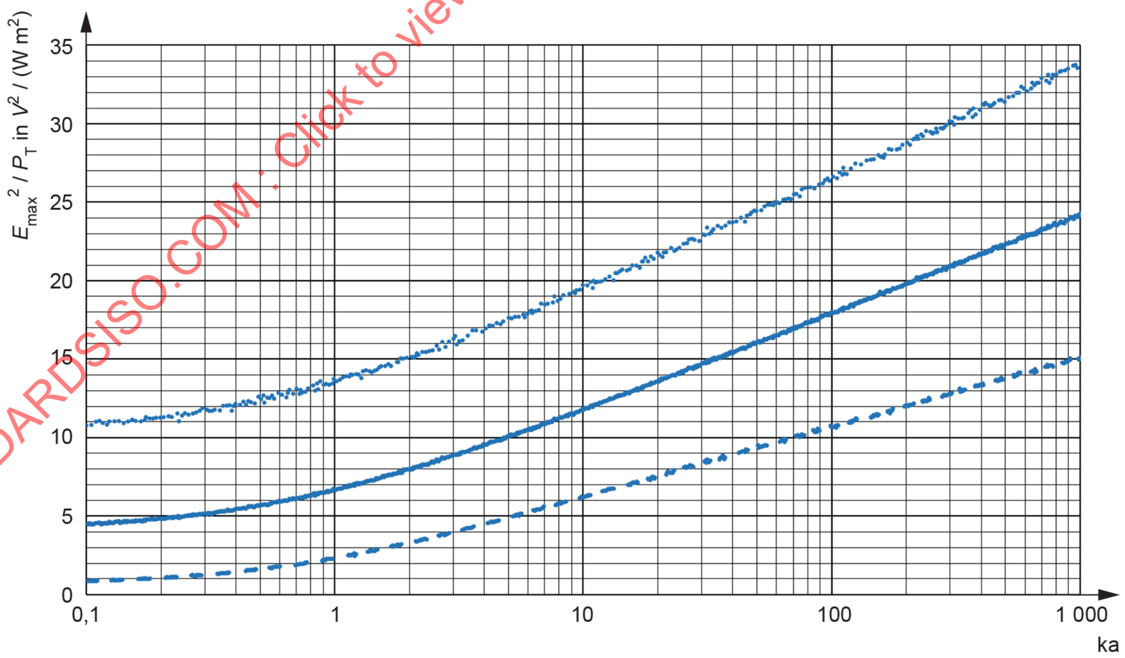
Table D.8 – Conversion factors (mean, quantile values, and standard deviation σ) for a = 2,5 m

f GHz	**1**			**3**			**6**		
Quantile	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB
95 %	24,65	13,92	1,11	27,8	14,44	0,997	29,97	14,77	0,93
mean	16,20	**12,10**		19,2	**12,83**		21,0	**13,22**	
5 %	9,70	9,87	1,35	11,66	10,67	1,29	13,1	11,17	1,26

Table D.9 – Example of disturbance limits for a = 0,75 m (EUT diameter 1,5 m) for the residential environment

f GHz	**1**	**3**	**3**	**6**
E_{limit} dB(µV/m)	50	50	54	54
$K(f)$ dB(Ω/m²)	11,14	11,98	11,98	12,50
P_{limit} dB(pW)	39	38	42	41
P_{limit} dBm	−51	−52	−48	−49

Figure D.5 (mean values) can be used for interpolation purposes if conversion factors for other EUT radii are to be determined.



NOTE Data for a = 0,75 m and 2,5 m, and 1 000 directivities (instead of 100 as in [19]) were provided by Dr. Magdowski using Krauthäuser's material.

Figure D.5 – Conversion factor (mean and quantile values) from FSOATS/FAR results to RC results for d = 3 m measurement distance as a function of electrical EUT size ka

The measurement results $M(f)$ and the deviations $D(f)$ in Equation (1) (see 6.4) and Equation (18) (see 7.2.1) are logarithmic quantities, and the conversion factors $\overline{K}(f)$ in Equation (12) (see 6.8) and Equation (19) (see 7.2.1) are mean values of logarithmic quantities; however, the conversion factor $K(f)$ in Equation (37) (see 8.1) and in this annex is the logarithm of the conversion factor $k(f)$, which is the mean value $\overline{K}(f)$ of individual linear conversion factors $k_i(f)$. Because the logarithm is a non-linear transformation, the difference between the logarithm of the mean of individual linear conversion factors $K_{\text{lin mean}}(f) = 10\lg\overline{k}(f) = 10\lg[1/N\sum_1^N k_i(f)]$ and the mean of individual logarithmic conversion factors $K_{\text{log mean}}(f) = \overline{K}(f) = 1/N\sum_1^N K_i(f) = 1/N\sum_1^N 10\lg k_i(f)$ is of interest. This difference was investigated by Dr. Magdowski using Krauthäuser's material with the results listed in Table D.10 and Table D.11, showing that the dispersion of conversion factors decreases with increasing frequency.

Table D.10 – Comparison of $K_{\text{lin mean}}(f)$ and $K_{\text{log mean}}(f)$ for the conversion of OATS/SAC (d = 10 m) results to RC results for a = 0,75 m

f/MHz	30	80	230	1 000
$K_{\text{lin mean}}(f)$/dB	0,84	2,73	5,52	7,86
$K_{\text{log mean}}(f)$/dB	−1,59	1,90	5,22	7,70

Table D.11 – Comparison of $K_{\text{lin mean}}(f)$ and $K_{\text{log mean}}(f)$ for the conversion of FOATS/FAR (d = 3 m) results to RC results for a = 0,75 m

f/GHz	1	3	6	10	40
$K_{\text{lin mean}}(f)$/dB	11,13	12,01	12,50	12,82	13,60
$K_{\text{log mean}}(f)$/dB	10,90	11,83	12,33	12,67	13,47

D.4 Instrumentation uncertainty for radiated disturbance measurement results in an RC

D.4.1 Measurand for radiated disturbance measurements using an RC

P Radiated power, in dB(pW),
against power limits converted from 10 m OATS/SAC results for 80 MHz to 1 000 MHz
against power limits converted from 3 m FSOATS/FAR results for 1 GHz to 18 GHz

NOTE Measurement results taken in a reverberation chamber are compared to the limit of radiated power defined in a product standard between 80 MHz and 1 GHz, and between 1 GHz and 6 GHz. 0 dB(µV) = −17 dB(pW) in a 50 Ω system.

D.4.2 Symbols of input quantities common to all disturbance measurements

a_{ca} attenuation of the connection between the receiver and the RC, in dB

δM correction for the error caused by mismatch, in dB

V_r receiver voltage reading, in dB(µV)

δV_{sw} correction for the receiver sine wave voltage inaccuracy, in dB

δV_{pa} correction for the imperfect receiver pulse amplitude response, in dB

δV_{pr} correction for the imperfect receiver pulse repetition rate response, in dB

δV_{nf} correction for the effect of the receiver noise floor, in dB

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D.4.3 Symbols of input quantities specific to RC measurements

F_{cv}	chamber validation factor, in dB
$\delta P_{nonunif}$	correction factor for the field non-uniformity in the EUT volume, in dB
$\delta P_{EUT\ size}$	correction factor for the deviation from the reference EUT size, in dB

D.4.4 Input quantities to be considered for radiated disturbance measurements using an RC

a) Receiver reading

b) Cable attenuation between RC and measuring receiver

c) Receiver related input quantities

   1) Sine wave voltage accuracy

   2) Pulse amplitude response

   3) Pulse repetition rate response

   4) Noise floor proximity

d) Mismatch effects between RC receiver port and measuring receiver

e) Chamber validation factor

f) Effect of field non-uniformity in EUT volume (see Annex B of IEC 61000-4-21:2011[22])

g) Effect of deviating directivity due to EUT size deviating from the assumed reference EUT size

D.4.5 Uncertainty budget for radiated disturbance measurement results using an RC

The measurand P is calculated using model Equation (D.3):

$$P = V_r + a_c + F_{cv} + \delta V_{sw} + \delta V_{pa} + \delta V_{pr} + \delta V_{nf} + \delta M + \delta P_{nonunif} + \delta P_{EUT\ size} - 17\ dB\Omega \qquad (D.3)$$

Table D.12 (80 MHz to 1 000 MHz) and Table D.13 (1 GHz to 6 GHz) show example uncertainty budgets for radiated disturbance measurement results using an RC.

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Table D.12 – Uncertainty budget for radiated disturbance measurement results using an RC from 80 MHz to 1 000 MHz (example)

Input quantity[a]	X_i	Uncertainty of x_i dB	Probability distribution function	$c_i\ u(x_i)$[b] dB
Receiver reading[D1)]	V_r	±0,1	k = 1	0,10
Attenuation: RC-receiver[D2)]	a_c	±0,2	k = 2	0,10
Receiver corrections:				
Sine wave voltage[D3)]	δV_{sw}	±1,0	k = 2	0,50
Pulse amplitude response[D4)]	δV_{pa}	±1,5	Rectangular	0,87
Pulse repetition rate response[D4)]	δV_{pr}	±1,5	Rectangular	0,87
Noise floor proximity[D5)]	δV_{nf}	±0,3	Rectangular	0,17
Mismatch: RC-receiver[D6)]	δM	+0,79/–0,87	U-shaped	0,58
Chamber validation factor[D7)]	F_{cv}	±1,5	k = 2	0,75
Field non-uniformity[D8)]	$\delta P_{nonunif}$	±3,5	k = 1	3,5
Deviation from reference EUT size[D9)]	$\delta P_{EUT\ size}$	±1,0	Rectangular	0,58

[a] Superscripts (e.g. [D1)]) correspond to the comments in D.4.6.

[b] All c_i = 1.

NOTE The distribution function is normal, unless otherwise expressed in the table.

Hence, the expanded uncertainty is $U(P) = 2u_c(P)$ = 7,82 dB.

Table D.13 – Uncertainty budget for radiated disturbance measurement results using an RC from 1 GHz to 6 GHz (example)

Input quantity[a]	X_i	Uncertainty of x_i dB	Probability distribution function	$c_i\ u(x_i)$[b] dB
Receiver reading[D1)]	V_r	±0,1	k = 1	0,10
Attenuation: RC-receiver[D2)]	a_c	±0,4	k = 2	0,20
Receiver corrections:				
Sine wave voltage[D3)]	δV_{sw}	±1,5	k = 2	0,75
Noise floor proximity[D5)]	δV_{nf}	+ 0,1/0,0	Rectangular	0,06
Mismatch: RC-receiver[D6)]	δM	+0,79/–0,87	U-shaped	0,58
Chamber validation factor[D7)]	F_{cv}	±1,5	k = 2	0,75
Field non-uniformity[D8)]	$\delta P_{nonunif}$	±2,0	k = 1	2,0
Deviation from reference EUT size[D9)]	$\delta P_{EUT\ size}$	±1,0	Rectangular	0,58

[a] Superscripts (e.g. [D1)]) correspond to the comments in D.4.6.

[b] All c_i = 1.

The distribution function is normal, unless otherwise expressed in the table.

Hence, the expanded uncertainty is $U(P) = 2u_c(P)$ = 4,84 dB.

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NOTE The expanded uncertainties per Table D.12 and Table D.13 are typical values only and are not intended to become values for U_{CISPR}.

D.4.6 Rationale for the estimates of input quantities for radiated disturbance measurement results using an RC

NOTE 1 Comments in D1) through D6) are adapted from CISPR 16-4-2 [24].

D1) Receiver readings will vary for reasons that include measuring system instability and meter scale interpolation errors. The estimate of V_r is the mean of many readings (sample size larger than 10) of a stable signal, with a standard uncertainty given by the experimental standard deviation of the mean (k = 1).

D2) An estimate of the attenuation a_c of the connection between the receiver and the RC is assumed to be available from a calibration report, along with an expanded uncertainty and a coverage factor.

NOTE 2 If the estimate of attenuation a_c is obtained from manufacturer's data for a cable or attenuator, a rectangular probability distribution having a half-width equal to the manufacturer's specified tolerance on the attenuation can be assumed. If the connection is a cable and attenuator in tandem, with manufacturer's data available on each, a_c has two components, each with its own rectangular probability distribution.

NOTE 3 In the frequency range below 30 MHz, the estimate of the expanded uncertainty is 0,1 dB, from 30 MHz to 1 000 MHz it is 0,2 dB, from 1 GHz to 6 GHz it is 0,3 dB, and from 6 GHz to 18 GHz it is 0,6 dB, with a coverage factor of 2. A lower estimate for this uncertainty contribution can be achieved using a vector network analyzer for the cable calibration.

D3) An estimate of the correction δV_{sw} for receiver sine-wave voltage inaccuracy is assumed to be available from a calibration report, along with an expanded uncertainty and a coverage factor.

NOTE 4 If a calibration report states only that the receiver sine-wave voltage accuracy is within the CISPR 16-1-1 tolerance (±2 dB), then the estimate of the correction δV_{sw} is taken as zero with a rectangular probability distribution having a half-width of 2 dB. If the calibration report states a value less than the CISPR 16-1-1 tolerance (e.g. ±1 dB), then the stated value is used in the uncertainty calculation, not the stated uncertainty value of the calibration process. If the calibration report provides detailed deviations from reference values, then the reported deviations and the uncertainties of the calibration laboratory can be used to determine the uncertainties of the measuring receiver.

D4) In general, it is impractical to correct for imperfect receiver pulse response characteristics.

The requirements in CISPR 16-1-1 shall be used as the reference for uncertainty estimation. A verification report stating that the receiver pulse amplitude response complies with the CISPR 16-1-1 tolerance of ±1,5 dB for peak, quasi-peak, average or RMS-average detection is assumed to be available. The correction δV_{pa} is estimated to be zero with a rectangular probability distribution having a half-width of 1,5 dB.

The CISPR 16-1-1 tolerance for pulse repetition rate response varies with repetition rate and detector type. A verification report stating that the receiver pulse repetition rate responses comply with the CISPR 16-1-1 tolerances is assumed to be available. The correction δV_{pr} is estimated to be zero with a rectangular probability distribution having a half-width of 1,5 dB, a value considered to be representative of the various CISPR 16-1-1 tolerances.

NOTE 5 If the pulse amplitude response or the pulse repetition rate response is verified to be within $\pm\alpha$ dB of the CISPR specification ($\alpha \leq 1{,}5$), the correction for that response can be estimated to be zero with a rectangular probability distribution having a half-width of α dB.

NOTE 6 If a disturbance produces a continuous wave signal at the detector, pulse response corrections are not considered.

D5) The noise floor of a CISPR receiver is compared with the RC output voltage level V_{lim} corresponding to the power limit P_{lim} in order to determine the signal-to-noise ratio.

Mean values for a = 0,75 m from Figure D.3 using Equation (35) (see 8.1) enable the calculation of P_{lim} in Table D.14.

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For radiated disturbance measurement using an RC below 1 GHz, the deviation δV_{nf} is estimated to be between zero and +0,6 dB. The correction is estimated to be zero as if the deviation would be symmetric around the value to be measured with a rectangular probability distribution having a half-width of 0,6 dB. Any correction for the effect of the noise floor would depend on the signal type (e.g. impulsive or unmodulated sinewave) and the signal-to-noise ratio and would change the noise level indication. The value of 0,6 dB is taken from Figure D.6 for a *S/N* = 22 dB. The *S/N* has been obtained for a noise figure of 6 dB, using Equation (D.4)

$$\begin{aligned} P_{NQP} &= V_{NQP} + a_{IL\,RC} + a_c - 17 \\ &= -67 + 10\lg F_N + 10\lg B_N + w_{NQP} + a_{IL\,RC} + a_c - 17 \end{aligned} \tag{D.4}$$

where

P_{NQP}	is the equivalent power of the quasi-peak noise floor, in dB(pW);
V_{NQP}	is the receiver quasi-peak noise floor, in dB(μV);
$a_{IL\,RC}$	is the RC insertion loss at the receive frequency, in dB;
a_c	is the attenuation of the receiver connecting cable, in dB;
F_N	is the noise factor of the measuring receiver, i.e. a number;
$10\lg F_N$	is the noise figure of the measuring receiver, in dB;
B_N	is the noise bandwidth of the measuring receiver, in Hz;
w_{NQP}	is the quasi-peak weighting factor of noise, in dB;
−67	is $10\lg(kT_0 \times 1\text{ Hz} / P_{1\mu V})$, the absolute noise level in dB(μV) in 1 Hz bandwidth, with k = Boltzmann's constant, T_0 = 293,15 K, and $P_{1\mu V}$ is the power generated by 1 μV across 50 Ω;
−17	is the conversion from dB(μV) to dB(pW) in a 50 Ω system (0 dB(μV) = −17 dB(pW)).

The worst-case *S/N* is obtained near 1 000 MHz. With $10\lg F_N$ = 6, $10\lg B_N$ = 50,8 (for 120 kHz), the weighting factor w_{NQP} being 7 dB, the RC insertion loss of $a_{IL\,RC}$ = 15 dB for 1 000 MHz (extrapolated from reference [21]), and the cable attenuation a_c = 2 dB, the quasi-peak noise indication in terms of power is P_{NQP} = −3 dB(pW). This is compared to a disturbance power at the disturbance limit of 29 dB(pW) to give a signal-to-noise ratio *S/N* of 32 dB. In the frequency range below 1 000 MHz, the *S/N* is higher, hence an *S/N* > 30 dB may be assumed.

For the FSOATS-based power limits (above 1 GHz), Figure D.4 is used, where d = 3 m to calculate P_{lim} using a = 0,75 m in Table D.15.

For radiated disturbance measurements above 1 GHz the limits apply for average and peak detectors; similar considerations for the noise floor as below 1 GHz apply. The stronger influence of noise and higher uncertainty caused by noise is with the peak detector.

Figure D.7 provides plots of the deviation from signal level as a function of *S/N*.

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The worst-case *S/N* is obtained near 6 GHz. With 10lg F_N = 6, 10lg B_N = 58,2 (corresponding to 0,66 MHz), the weighting factor w_{NPk} being 11 dB, the RC insertion loss of $a_{IL\ RC}$ = 31 dB for 6 GHz, and the cable attenuation a_c = 2 dB, the peak noise indication in terms of power is P_{NQP} = 24 dB(pW). This is compared to a disturbance power level of 62 dB(pW) at the disturbance limit (corresponding to 74 dB(μV/m) at 3 m distance) to give a signal-to-noise ratio *S/N* of 38 dB. In the frequency range below 6 GHz, the *S/N* is higher, hence an *S/N* > 38 dB may be assumed. From Figure D.7 a maximum deviation for sine waves of 0,1 dB can be read.

Table D.14 – Values of P_{lim} for 30 MHz to 1 000 MHz (E_{lim} from [20])

Frequency MHz	E_{lim} dB(μV/m)	P_{lim} dB(pW)
80	30	27,0
230	30	25,0
230	37	32,0
1 000	37	29,0

Table D.15 – Values of P_{lim} for 1 GHz to 6 GHz (E_{lim} from [20])

Frequency MHz	E_{lim} dB(μV/m)	P_{lim} dB(pW)
1	50	39
3	50	38
3	54	42
6	54	42

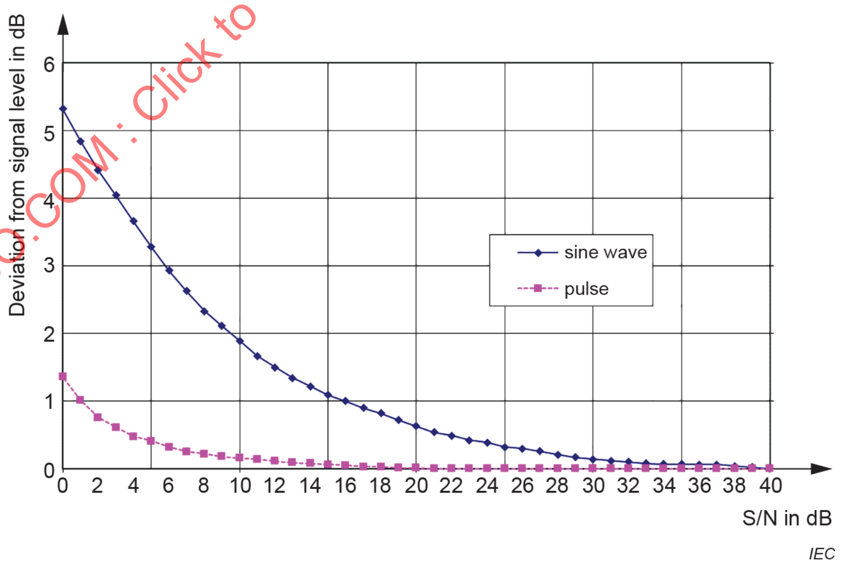

Figure D.6 – Deviation of the QP detector level indication from the signal level at receiver input for two cases: sine-wave signal, and impulsive signal (PRF 100 Hz)

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