CISPR TR 16-4-4

Edition 2.2 2020-04
CONSOLIDATED VERSION

TECHNICAL REPORT

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

Specification for radio disturbance and immunity measuring apparatus and methods –
Part 4-4: Uncertainties, statistics and limit modelling – Statistics of complaints and a model for the calculation of limits for the protection of radio services

colour inside

CISPR TR 16-4-4:2007-07+AMD1:2017-06+AMD2:2020-04 CSV(en)

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FOREWORD

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This consolidated version of the official IEC Standard and its amendments has been prepared for user convenience.

CISPR 16-4-4 edition 2.2 contains the second edition (2007-07) [documents CISPR/H/147/DTR and CISPR/H/153/RVC], its amendment 1 (2017-06) [documents CIS/H/313/DTR and CIS/H/319/RVC] and its amendment 2 (2020-04) [documents CIS/H/402/DTR and CIS/H/407A/RVDTR].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendments 1 and 2. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

This second edition of CISPR 16-4-4, which is a technical report, has been prepared by CISPR subcommittee H: Limits for the protection of radio services.

This second edition of CISPR 16-4-4 contains two thoroughly updated Clauses 4 and 5, compared with its first edition. It also contains, in its new Annex A, values of the classical CISPR mains decoupling factor which were determined by measurements in real LV AC mains grids in the 1960s. It is deemed that these mains decoupling factors are still valid and representative also for modern and well maintained LV AC mains grids around the world.

The information in Clause 4 – Statistics of complaints and sources of interference – was accomplished by the history and evolution of the CISPR statistics on complaints about radio frequency interference (RFI) and by background information on evolution in radio-based communication technologies. Furthermore, the forms for collation of actual RFI cases were detailed and structured in a way allowing for more qualified assessment and evaluation of compiled annual data in regard to the interference situation, as e.g. fixed or mobile radio reception, or analogue or digital modulation of the interfered with radio service or application concerned.

The information in Clause 5 – A model for the calculation of limits – was accomplished in several ways. The model itself was accomplished in respect of the remote coupling situation as well as the close coupling one. Further supplements of this model were incorporated regarding certain aspects of the coupling path via induction and wave propagation (radiation) of classical telecommunication networks. Furthermore, the calculation model on statistics and probability underwent revision and was brought in line with a more modern mathematical approach. Eventually the present model was extended for a possible determination of CISPR limits in the frequency range above 1 GHz.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the stability date indicated on the IEC web site 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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SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 4-4: Uncertainties, statistics and limit modelling – Statistics of complaints and a model for the calculation of limits for the protection of radio services

1 Scope

This part of CISPR 16 contains a recommendation on how to deal with statistics of radio interference complaints. Furthermore it describes the calculation of limits for disturbance field strength and voltage for the measurement on a test site based on models for the distribution of disturbances by radiated and conducted coupling, respectively.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-161*, International Electrotechnical Vocabulary (IEV) – Part 161: Electromagnetic compatibility* (available at http://www.electropedia.org)

CISPR 11, *Industrial, scientific and medical ~~(ISM) radio-frequency~~ equipment – ~~Electromagnetic~~ Radio-frequency disturbance characteristics – Limits and methods of measurement*

CISPR 16-4-3, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-3: Uncertainties, statistics and limit modelling – Statistical considerations in the determination of EMC compliance of mass-produced products*

CISPR 15:2018, *Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-161 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
complaint
~~a~~ request for assistance made to the RFI investigation service by the user of a radio receiving equipment who complains that reception is degraded by radio frequency interference (RFI)

3.1.2
RFI investigation service
institution having the task of investigating reported cases of radio frequency interference and which operates at the national basis

~~NOTE~~ EXAMPLE ~~Examples include a~~ Radio service provider, ~~a~~ CATV network provider, ~~an~~ administration, ~~or a~~ regulatory authority.

3.1.3
source
any type of electric or electronic equipment, system, or (part of) installation emanating disturbances in the radio frequency (RF) range which can cause radio frequency interference to a certain kind of radio receiving equipment

3.2 Symbols and abbreviated terms

E_{ir}	permissible interference field strength at the point A in space where the antenna of the victim receiver is located – without consideration of probability factors
E_{Limit}	permissible interference field strength at the point A in space where the antenna of the victim receiver is located – with consideration of probability factors
R_P	protection ratio
C_{PV}	coupling factor describing the proportionality of the field strength E with the square root of the power P injected as common mode into the radiating structure by the apparatus (GCPC)
Group A	defined PV generator group for single-family detached houses
Group B	defined PV generator group for multi-storey buildings with flat roof tops
Group C	defined PV generator group for sun tracking supports ("trees")
Group D	defined PV generator group for large barns in the countryside
ρ_i	probability of an individual PV generator being a member of Group i
$\bar{C}_{PV}$	group-independent mean value for the coupling factor
P_S	disturbance power emitted by a GCPC with the complex source impedance Z_S
P_L	power injected into the PV generator eventually radiated via that installation
P_{TC}	disturbance power determined at the DC-AN on a standardized test site according to CISPR 11 with fixed impedance Z_{TC} = 150 Ω
U_{Limit}	permitted disturbance voltage limit
P_7	probability for time coincidence (μ_{P7} in dB)
P_8	probability for location coincidence (μ_{P8} in dB)
P_4	probability for frequency coincidence inclusive harmonics(μ_{P4} in dB)
m_L	mismatch loss in use case (between the GCPC with complex source impedance Z_S and the PV generator with complex load impedance Z_L)
m_{TC}	mismatch loss in test case (between the GCPC with complex source impedance Z_S and the DC-AN according to CISPR 11 with measurement impedance fixed to Z_{TC} = 150 Ω)
AMN	artificial mains network
CM	common mode
DC-AN	DC artificial network
DM	differential mode

GCPC grid connected power converter

S/N noise power/signal power

4 Statistics of complaints and sources of interference

4.1 Introduction and history

The previous edition of CISPR 16-4-4 contained, in its Clause 4, a complete reprint of CISPR Recommendation 2/3 on statistics of complaints and sources of interference. However, due to modern technological evolution in radio systems directed towards introduction of digital radio services, and due to increasing use of mobile and portable radio appliances by the public, the traditional CISPR statistics of complaints on radio frequency interference are experiencing a decreasing significance as an indicator of the quality of standardisation work for the protection of radio services and applications. That is why related information in this edition of CISPR 16-4-4 is reduced to the necessary minimum allowing interested parties to continue their complaint-based collation of data on an annual basis.

In order to accommodate the evolution in modern radio technology and mobile and portable use of radio receiving equipment, it may be necessary to replace or to gather the complaints-based CISPR statistics by other more modern statistics or means. These new statistics should be based on a systematic annual collation of data about degradation of quality of radio services and reception due to electromagnetic disturbances occurring in the environment. These data will have to be collected and processed, however, primarily by the radio service providers themselves.

4.2 Relationship between radio frequency interference and complaints

Whatever the radio system involved, official complaints usually represent only a small subset of all occurring interference situations. Occasional interference generally does not lead to an official complaint if its duration is brief or if it happens only once in a while. It is only when the same interference situation occurs repetitively that an official complaint is reported. This situation also greatly depends on the conditions of use (fixed or mobile) of the victim radio system.

4.2.1 Radio frequency interference to a fixed radio receiver

Before the wide development of portable radio devices, radio systems that suffered from interference were generally used in fixed locations. This is the case, for example for a TV set in a flat or home: if this TV set is regularly interfered with by radiation or conduction from other equipment located inside or just outside the house, then it is probable that a complaint will be issued. The same applies if a satellite antenna, a fixed radio link, or a cellular phone base station suffers from radio frequency interference.

4.2.2 Radio frequency interference to a mobile radio receiver

The multiplication of portable radio systems such as cellular phones and short range radio systems has changed the conditions regarding interference situations and interference complaints. The ability for the user to move makes it easier to resolve a particular interference case, but makes it more difficult to recognise that an interference case has actually occurred.

4.2.3 Consequences of the move from analogue to digital radio systems

In addition to the conditions of use of the victim radio system, technological evolution in radio services with successive phasing out of analogue and exponential growth of digital applications also has consequences on the number of reported interference cases.

If a digital mobile phone or a wireless LAN receiver cannot receive the signal from the nearest base station or access point because of an unwanted emission from a nearby equipment, the user will never suspect this equipment and will not even consider the possibility of an interference occurring. He will assume that the coverage of the network is poor and will move to another place to make his call or to get his connection. Furthermore, as these systems are generally frequency agile, if one channel is interfered with, the system will choose another channel, but if all other channels are occupied, then the phone will indicate that the network is busy, and once again, the user will think the network capacity is not large enough to accommodate his call, but he will never suspect an EMC problem.

Generally for analogue systems, one can hear the interference. With digital and mobile systems, interference is much less noticeable (muting in audio reception, or frozen images on the TV set for DVB). In addition, modern digital modulations implement complex escape mechanisms (data error correction, frequency agile systems, etc.) so that the system can already be permanently affected from an EMC point of view before an interference case is actually detected.

4.3 Towards the loss of a precious indicator: interference complaints

The evolutions detailed above – generalisation of mobile use of radio receivers and the move from analogue to digital radio services – will not reduce the number of interference situations, but continues to decrease the probability of getting significant numbers of interference complaints indicating an existing EMC problem. So, along with the growing development of portable digital radio devices, the usefulness of traditional interference complaints statistics to support the CISPR work will continue to diminish in importance.

4.4 CISPR recommendations for collation of statistical data on interference complaints and classification of interference sources

Considering

a) that RFI investigation services may whish to continue publication of statistics on interference complaints;

b) that it would be useful to be able to compare the figures for certain categories of sources;

c) that varied and ambiguous presentation of these statistics often renders this comparison difficult,

CISPR recommends

(1) that the statistics provided to National Committees should be in such a form that the following information may be readily extracted:

(1.1) the number of complaints as a percentage of the total number of sound broadcast receivers or television broadcast receivers or other radio communication receivers in operation in a certain country, or region;

(1.2) the relative aggressivity of the various sources of interference in the different frequency bands;

(1.3) the comparison of the interference caused by the same source in different frequency bands;

(1.4) the effectiveness of limits (CISPR or national) and other counter-measures on items (1.1), (1.2), and (1.3);

(1.5) the number of sources of the same type involved in a certain interference case. Interference may be caused by a group of devices, for example, a number of fluorescent lamps on one circuit. In such cases, the number to be entered into the statistics is determined by the RFI investigation service.

NOTE To facilitate comparison of statistics, the method used to determine the number of sources should be stated.

One source may cause many complaints and one complaint may be caused by more than one source. Therefore it is clear that the number of sources and the number of complaints against any classification code may not be related.

For the purpose of these statistics, active generators of electrical energy and apparatus and installations which cause interference by secondary effects (secondary modulation) are included. See also appliances of category B in Table 1;

(1.6) causes of complaints not related to a source, as e.g. unsatisfactory radio reception due to a lack of immunity of the radio receiving installation or a lack of coverage with wanted radio signals, see also appliances of category K in Table 1;

(2) that statistics should cover a complete calendar year; they should whenever possible be presented in the following form, see standard forms in Figures 1a to 1d, without necessarily employing more detailed categories than listed in Table 1. It is however not intended to exclude further subdivisions; these may be desirable, but they should fit into the scheme of the standard forms set out below; the code numbers refer to the items listed in Table 1.

4.5 Forms for statistics of interference complaints

1	**Radio services with analogue modulation**									
1.1	**Fixed or stationary radio reception**									
Source of interference or other cause of complaint					**Number of complaints per radio service from each source**					
Classification code			**Description**	**Total number in each identification**	**Broadcasting** [a]					**Other services** [b]
					Sound [c]		**Television** [c]			
					LF/ MF/ HF	**II**	**I**	**III**	**IV/V**	
A	1	1								
	2	1								
		etc. as indicated in Table 1								
1.1	Fixed or stationary radio reception, analogue modulation			Totals						

a LF = low radio frequency (long waves);
MF = medium radio frequency (medium waves);
HF = high radio frequency (short waves).
These three bands may either be grouped together, as shown, or dealt with separately.
II = Band II (VHF/sound broadcasting);
I = Band I (VHF/television broadcasting);
III = Band III (VHF/television broadcasting);
IV/V = Band IV/V (UHF/television broadcasting).

b The service and band affected should be stated.

c At the time of receipt of complaints of interference, i.e. before they have been investigated fully, it may not be possible to apportion the complaints accurately to the various broadcasting services. If this is so, then the number of complaints should be stated separately for sound broadcasting and television broadcasting.

IEC 1182/07

Figure 1a – Standard form for statistics on interference complaints recommended for radio services with analogue modulation and fixed or stationary radio reception

1	**Radio services with analogue modulation**								
1.2	**Mobile or portable radio reception**								
Source of interference or other cause of complaint					**Number of complaints per radio service from each source**				
Classification code			**Description**	**Total number in each identification**	**Broadcasting** [a]				**Other services** [b]
					Sound [c]		**Television** [c]		
					LF/ MF/ HF	**II**	**I**	**III**	**IV/V**
A	1	1							
	2	1							
		etc. as indicated in Table 1							
1.2	Mobile or portable radio reception, analogue modulation			Totals					

a LF = low radio frequency (long waves);
MF = medium radio frequency (medium waves);
HF = high radio frequency (short waves).
These three bands may either be grouped together, as shown, or dealt with separately.
II = Band II (VHF/sound broadcasting);
I = Band I (VHF/television broadcasting);
III = Band III (VHF/television broadcasting);
IV/V = Band IV/V (UHF/television broadcasting).

b The service and band affected should be stated.

c At the time of receipt of complaints of interference, i.e. before they have been investigated fully, it may not be possible to apportion the complaints accurately to the various broadcasting services. If this is so, then the number of complaints should be stated separately for sound broadcasting and television broadcasting.

IEC 1183/07

Figure 1b – Standard form for statistics on interference complaints recommended for radio services with analogue modulation and mobile or portable radio reception

<table>
<tr><td colspan="2">2</td><td colspan="9">Radio services with digital modulation</td></tr>
<tr><td colspan="2">2.1</td><td colspan="9">Fixed or stationary radio reception</td></tr>
<tr><td colspan="5">Source of interference
or other cause of complaint</td><td colspan="6">Number of complaints per radio service
from each source</td></tr>
<tr><td colspan="3" rowspan="3">Classification code</td><td rowspan="3">Description</td><td rowspan="3">Total number in each identification</td><td colspan="5">Broadcasting [a]</td><td rowspan="2">Other services [b]</td></tr>
<tr><td>Sound [c]</td><td colspan="4">Television [c]</td></tr>
<tr><td>LF/ MF/ HF</td><td>II</td><td>I</td><td>III</td><td>IV/V</td><td></td></tr>
<tr><td>A</td><td>1

2</td><td>1

1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">etc. as indicated in Table 1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2.1</td><td colspan="3">Fixed or stationary radio reception, digital modulation</td><td>Totals</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="11">a LF = low radio frequency (long waves);
MF = medium radio frequency (medium waves);
HF = high radio frequency (short waves).
These three bands may either be grouped together, as shown, or dealt with separately.
II = Band II (VHF/sound broadcasting);
I = Band I (VHF/television broadcasting);
III = Band III (VHF/television broadcasting);
IV/V = Band IV/V (UHF/television broadcasting).
b The service and band affected should be stated.
c At the time of receipt of complaints of interference, i.e. before they have been investigated fully, it may not be possible to apportion the complaints accurately to the various broadcasting services. If this is so, then the number of complaints should be stated separately for sound broadcasting and television broadcasting.</td></tr>
</table>

IEC 1184/07

Figure 1c – Standard form for statistics on interference complaints recommended for radio services with digital modulation and fixed or stationary radio reception

2	**Radio services with digital modulation**									
2.2	**Mobile or portable radio reception**									
Source of interference or other cause of complaint					**Number of complaints per radio service from each source**					
Classification code			**Description**	**Total number in each identification**	**Broadcasting** [a]					**Other services** [b]
					Sound [c]		**Television** [c]			
					LF/ MF/ HF	**II**	**I**	**III**	**IV/V**	
A	1	1								
	2	1								
		etc. as indicated in Table 1								
2.2	Mobile or portable radio reception, digital modulation			Totals						

a LF = low radio frequency (long waves);
MF = medium radio frequency (medium waves);
HF = high radio frequency (short waves).
These three bands may either be grouped together, as shown, or dealt with separately.
II = Band II (VHF/sound broadcasting);
I = Band I (VHF/television broadcasting);
III = Band III (VHF/television broadcasting);
IV/V = Band IV/V (UHF/television broadcasting).

b The service and band affected should be stated.

c At the time of receipt of complaints of interference, i.e. before they have been investigated fully, it may not be possible to apportion the complaints accurately to the various broadcasting services. If this is so, then the number of complaints should be stated separately for sound broadcasting and television broadcasting.

IEC 1185/07

Figure 1d – Standard form for statistics on interference complaints recommended for radio services with digital modulation and mobile or portable radio reception

Figure 1 – Standard forms for statistics on interference complaints

For RFI investigation services which would like to issue reports on statistics of interference complaints it is recommended to use the classification of interference sources set out in Table 1. Use of this classification will facilitate comparison of RFI situations observed in different countries.

Table 1 – Classification of sources of radio frequency interference and other causes of complaint

Classification code	Description of the source
A	**Industrial, scientific, and medical (ISM) RF apparatus (CISPR 11)**
A.1	Industrial, scientific, and medical (ISM) RF apparatus (group 2) inclusive microwave ovens and RF lighting appliances
A.2	Other industrial or similar apparatus (group 2) as e.g. arc welding equipment or spark generating apparatus (EDM), etc.
A.3	Other industrial or similar apparatus (group 1) as e.g. generators, motors, convertors, semiconductor controlled devices, etc.
B	**Electric power supply, distribution and electric traction (CISPR 11, CISPR 18)**
B.1	Power supply installations (AC or DC voltages exceeding 100 kV) as e.g. overhead power lines, generating and switching stations, converting stations, etc.
B.2	Power supply installations (AC or DC voltages 1 kV to 100 kV) as e.g. overhead power lines, generating and switching stations, converting stations, etc.
B.3	Low voltage (LV) power supply and distribution (AC or DC voltages up to 1 kV)
B.4	Electric traction as e.g. for railways, tramways, or trolley buses
C	**Low power appliances as normally used in households, offices and small workshops (CISPR 14)**
C.1	Motors in household appliances e.g. in electric tools, vacuum cleaners, etc.
C.2	Contact devices, thermostats, etc.
C.3	Semiconductor controlled appliances (less than 1 kW load)
D	**Gaseous discharge and other lamps and luminaries (CISPR 15)**
	Fluorescent lamps and luminaries, neon advertising signs, self-ballasted lamps, etc.
E [a]	**Radio broadcast receiving installations (CISPR 13, CISPR 25)**
E.1	Sound broadcast receivers for fixed or mobile use
E.2	Television broadcast receivers for fixed or mobile use
E.3	Cable television installations (CATV)
F [a]	**Radio communication systems (ITU Recommendations)**
F.1	Radio broadcast or communication transmitters for fixed or mobile use
F.2	Radio communication receivers for fixed or mobile use
G	**Ignition systems of internal combustion engines (CISPR 12)**
	Cars, motor bikes, boats, trucks, etc. if propelled by electrical means or internal combustion engines or both, exclusive electric traction vehicles
H	**Information and communication technology (ICT) appliances (CISPR 22)**
H.1	Wire-bound telecommunication terminal equipment (TTE) and telecommunication equipment (TE) in the infrastructure of networks as e.g. in telecommunication centres, wire-bound LAN, etc.
H.2	Data processing equipment (DPE) such as e.g. computers and ancillary equipment
H.3	Radiation from wire-bound telecommunication networks
J	**Identified sources other than those specified (IEC 61000-6-3 and IEC 61000-6-4)**
K	**Other causes of complaint**
K.1	Lack of immunity of radio receiving installations or other appliances
K.2	Lack of coverage of wanted radio service (weak or faulty wanted signals)

[a] Only those complaints belong to the statistics where a radio broadcast receiving installation (E) or a component of a radio communication system (F) was identified as causing the interference.

5 A model for the calculation of limits

5.1 Introduction

A harmonized method of calculation is an important precondition for the efficient discussion of CISPR limits by National Committees and the adoption of CISPR publications.

5.1.1 Generation of EM disturbances

CISPR publications are developed for protection of radio communications and often several types of radio networks are to be protected by a single emission limit.

Most electrotechnical equipment has the potential to interfere with radio communications. Coupling from the source of electromagnetic disturbance to the radio communications installation may be by radiation, induction, conduction, or a combination of these mechanisms. Control of the pollution of the radio spectrum is accomplished by limiting at the source the levels of appropriate components of the electromagnetic disturbances (voltage, current, field strength, etc.). The choice of the appropriate component is determined by the mechanism of coupling, the effect of the disturbance on radio communications installations and the means of measurement available.

5.1.2 Immunity from EM disturbances

Most radio receiving equipment has the potential to malfunction as the result of being subjected to EM disturbances.

Protection of equipment is accomplished by hardening the appropriate disturbance entry route except for the antenna input port, for in-band disturbances. The choice is determined by the mechanism of coupling, the effect of the disturbance on the electronic equipment and the means of measurement available.

5.1.3 Planning a radio service

Before planning a radio communication service, it is necessary to decide upon the reliability of obtaining a predetermined quality of reception. This condition can be expressed in terms of the probability of the actual signal-to-interference ratio R at the antenna input port of a receiver being greater than the minimum permissible signal-to-interference ratio R_p needed to get a predetermined quality of reception α. That is:

$$P\left[R(\mu_R;\sigma_R) \geq R_p\right] = \alpha$$

where

$P[\ ]$ is the probability function;

$R(\mu_R;\sigma_R)$ is the actual signal-to-interference ratio as a function of its mean value (μ_R) and standard deviation (σ_R);

R_p is the minimum permissible signal-to-interference ratio (protection ratio);

α is a specified value representing the reliability of communications.

This probability condition is the basis for the method of determining limits.

5.2 Probability of interference

In order to make recommendations to protect adequately the radio communications systems of interest to the ITU, considerable attention is paid within CISPR to the probability of interference occurring. The following is an extract from CCIR Report 829 [1)].

5.2.1 Derivation of probability of interference

The Radio Regulations, Volume 1, Chapter I, Definition 1.166, defines interference as “the effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radio communication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy”.

5.2.1.1 Probability of instantaneous interference

Let

A denote "The desired transmitter is transmitting";

B denote "The wanted signal is satisfactorily received in the absence of unwanted energy";

C denote "Another equipment is producing unwanted energy";

D denote "The wanted signal is satisfactorily received in the presence of the unwanted energy".

All of these statements refer to the same small-time period. Then, according to the definitions, interference means "A and B and C and D*", where D* is the negation or opposite of D: Let $P(x)$ denote the "probability of x" and $P(x \mid y)$ denote the "probability of x, given y". Then, the probability of interference during the small-time period is

$$P(\text{I}) = P(\text{A and B and C and D*}) \quad (1)$$

It can be shown that this can be expressed in terms of known or computable quantities:

$$P(\text{I}) = [P(\text{B} \mid \text{A}) - P(\text{D} \mid \text{A and C})]\, P(\text{A and C}) \quad (2)$$

It may be preferable to consider the probability of interference only during the time that the wanted transmitter is transmitting. This probability is:

$$P'(\text{I}) = P(\text{B and C and D*} \mid \text{A}) \quad (3)$$

which can be reduced to:

$$P'(\text{I}) = [P(\text{B} \mid \text{A}) - P(\text{D} \mid \text{A and C})]\, P(\text{C} \mid \text{A}) \quad (4)$$

5.2.1.2 Discussion of Equations (2) and (4)

First, consider the difference between Equations (2) and (4). The probability of interference can be interpreted as the fraction of time that interference exists. In Equation (2), this fraction is the number of seconds of interference during a time period divided by the number of seconds the wanted transmitter is transmitting during the time period. This second fraction is larger than the first unless the wanted transmitter is on all the time. $P(\text{B} \mid \text{A})$ is just the probability that a wanted signal will be correctly received when there is no interference, often expressed as the probability that $S/N \geq R$ where S is the signal power, N is the noise power, and R is the signal-to-noise ratio required for satisfactory service. In some services, this probability is called the reliability, and is often computed when the system is designed. It can

[1)] The former CCIR Reports 656, 670, and 829 are no longer available.

be computed if system parameters (for example, transmitter and receiver location, power, required *S*/*N*) are known using statistical data on transmission loss (for example, Recommendation 370 [2]) and statistical data on radio noise (for example, ITU-R Rec. P.372-6 and Report 670 [3]).

Many systems, such as satellite or microwave relay point-to-point systems, are designed so that $P(B|A) \approx 1$. In other services, such as long-distance ionospheric point-to-point services, or mobile services near the edge of the coverage area, $P(B|A)$ may be quite small. In this latter case, the probability of interference will not be small regardless of the other probabilities.

$P(D|A$ and $C)$ is the probability that the wanted signal will be correctly received even when the unwanted energy is present. It can be computed if there is sufficient information about the location, frequency, power, etc. of the source of unwanted energy. For examples, see the references in Report 656 [3].

Notice that it has been assumed that $P(D|A$ and $C) \leq P(B|A)$; that is, if the signal can be received satisfactorily in the presence of unwanted energy, then it can surely be received satisfactorily in the absence of the unwanted energy. Thus $P(I)$ cannot be negative.

$P(A$ and $C)$ is the probability that the wanted transmitter and the source of unwanted energy are on simultaneously. In some situations, the wanted transmitter and source of unwanted energy may be operated independently. For example, they may be on adjacent channels, or beyond a coordination distance. In this case, $P(A$ and $C) = P(A)P(C)$, where $P(A)$ is the fraction of time that the wanted transmitter is emitting, and $P(C)$ is the fraction of time that the unwanted source is on.

In other situations, the operation may be highly dependent. For example, the transmitters may be co-channel stations in a disciplined mobile service. In this case $P(A$ and $C)$ is very small, but perhaps not zero, because a station can be located so that it causes interference even when it cannot hear the other transmitter.

The two transmitters might both operate continuously. For example, one might be part of a microwave point-to-point service, and the other a satellite sharing the same frequency band. In this case, $P(A$ and $C) = 1$, and the probability of interference depends entirely on the factor in square brackets in Equation (2).

Similarly, $P(C|A) = P(C)$ if the transmitters operate independently. $P(C|A)$ is very small if the two transmitters are co-channel stations in a disciplined land mobile service; and $P(C|A) = 1$ if the unwanted transmitter is on all the time.

In general, all the terms in Equations (2) and (4) affect the probability of interference, although their relative importance is different in different services.

5.3 Circumstances of interferences

In this part, general criteria are laid down for establishing disturbance limits for the purpose of preventing radio frequency interference (RFI) to happen. In this case, a distinction is made for areas where close coupling exists between noise sources and victim equipment, and for areas with remote coupling.

[2] ITU-R Rec. P.370-7, *VHF and UHF propagation curves for the frequency range from 30 to 1000 MHz. Broadcasting Services* was withdrawn in 2001.

[3] The former CCIR Reports 656, 670, and 829 are no longer available.

5.3.1 Close coupling and remote coupling

Although an ill-defined borderline exists between areas of close and remote coupling these concepts are generally used in the following terms.

Close coupling refers to a short distance between noise source and receiving antenna (for example, 3 m to 30 m) which is the case for residential sources interfering with broadcasting and land mobile receivers in residential areas. In general, frequencies up to 300 MHz are considered.

Remote coupling refers to longer distances, usually in the range of 30 m to 300 m, which are normal between professional or semi-professional sources and receivers as in the case of individual areas. The relevant frequency spectrum is much broader: 9 kHz to 18 GHz.

For the statements given above, it follows that some similarity exists between close coupling and near-field radiation conditions on the one hand and between remote coupling and far-field radiating conditions on the other hand. However, these concepts do not fully correspond since at frequencies below 1 MHz remote coupling may occur under near-field conditions whereas for frequencies above about 30 MHz close coupling may occur under far-field conditions. In the majority of practical situations, however, the good correspondence between close/remote coupling and near/far-field conditions is useful in evaluation of coupling aspects.

It should be noted that field-strength measurements, which are normally used for evaluating remote coupling characteristics, are actually carried out under near-field conditions in the lower end of the frequency range.

Whereas close and remote coupling are generally used to describe a direct coupling path between noise source and receiving antenna by means of electric, magnetic or radiation fields, an additional coupling mode is conduction coupling. In this case, the noise signal is conducted by the mains network from the mains output of the source to the mains input of the receiver, see also Figure 3, paths a1 and a2. Inside the receiver the noise signal is coupled from the mains port(s) to sensitive circuits of the receiver, as e.g. to its antenna port, or to its IF amplifier circuitry. This must be taken into account when determining the receiver's immunity requirements to injected in-band RF disturbances at its mains port.

Some well-known differences exist between near-field and far-field radiation characteristics, and therefore also for most close and remote coupling cases.

– Under far-field conditions with free-space propagation the relation between electric and magnetic components of the field is fixed and well defined, the relation under near-field conditions is rather undefined, if the source and coupling path characteristics are not known.
– Under far-field conditions the attenuation formula is

$$a = \frac{E_1}{E_2} \mathrm{k} \left(\frac{d_2}{d_1}\right)^x, \qquad \text{or} \qquad a = \frac{H_1}{H_2} \mathrm{k} \left(\frac{d_2}{d_1}\right)^x \tag{5}$$

NOTE The attenuation factor *a* describes the relation of the field strength E_1 (or H_1) found at distance d_1 to the field strength E_2 (or H_2) found at distance d_2. Factor k may e.g. be interpreted as an additional attenuation factor introduced by a wall allocated between the measurement locations at distances d_1 and d_2.

where

a = attenuation factor;

E_1, H_1 = absolute value of the field strength observed at a location still in the far field, but close to the source;

E_2, H_2 = absolute value of the field strength observed at a location in a more remote distance d_2 than d_1, from the source;

k = correction factor (in the range 1 to 10) counting e.g. for the screening effectiveness of buildings the noise source is allocated in, or for other absorbing obstacles allocated in between the considered locations at the distances d_1 and d_2;

d_1 = small distance in the far field range, but close to the location of the source;

d_2 = measurement distance more remote from the source;

x = propagation coefficient, which is 1 in free-space propagation and somewhat higher (1 to 1,5) for non-free-space propagation.

Under near-field conditions the propagation coefficient x is more complex and dependent on the magnetic or electric component with typical values between 2 and 3.

For this reason, it is much easier to develop a model for remote coupling conditions than for close coupling situations and for conduction coupling paths. Such a model is necessary to derive emission limits for a general interference environment.

5.3.2 Measuring methods

The measuring method is of major importance for specification of a radio frequency disturbance limit. Several measuring methods are applied and a short survey is given in the following paragraphs. In all measurements, the measuring instrument is a selective microvoltmeter (CISPR receiver) as specified for the relevant frequency range.

5.3.2.1 Disturbance voltage/current at mains ports

In the lower frequency range up to about 30 MHz, the mains network may conduct any injected RF energy to nearby users connected to the mains and/or couple part of the RF energy to nearby antennas in the electric, magnetic or radiation mode. Electric or magnetic field coupling to nearby antennas in this frequency range, however, is in most cases of minor importance compared with conduction coupling through the mains network. Because of the RF output voltage conduction mainly coupling through the mains network, the RF output voltage at the mains port is used as a measure for the interfering potential of almost any type of source in this frequency range. This permissible RF output disturbance voltage at the mains port of the source determines the minimum immunity requirements of the victim receiver against injected in-band RF disturbances at the receiver's mains port.

This disturbance voltage at mains ports is measured by means of an artificial mains network which isolates the source from the mains at RF frequency and which furnishes a standardized RF load to the source. For measurement of conducted disturbances, the artificial mains network generally recommended by CISPR is a 50 Ω/50 μH V-network which introduces a parallel impedance of 50 Ω/50 μH between each live or neutral wire of the mains port and reference ground.

Although not recommended by CISPR yet, the asymmetric current in the mains cable, measured by means of a current probe, might be used as a measure for the radiation capability of the source as already specified for telecommunication lines.

Current probe measurements of the asymmetric disturbance current in the mains cable require the mains port to be terminated with a suitable artificial mains network. This network should simulate the typical common mode impedance and RF unbalance (e.g. given as longitudinal conversion loss (LCL)) of the mains network and should decouple incoming common mode disturbances from the mains network side.

5.3.2.2 Disturbance voltage at signal ports

Imperfections of the symmetry in circuits carrying wanted symmetrical signals will produce unwanted asymmetric signals at the related ports and cables connected thereto. In asymmetric (coaxial) ports unwanted external currents can be conducted in the outer surface of the screen because of imperfect screening. These asymmetric signals and external screen currents may couple energy by inductive or radiation fields to nearby or remote antennas.

The asymmetric voltages can be measured by means of an artificial loading network. In this case the use of an asymmetric artificial network (AAN) instead of a V-network is preferred.

5.3.2.3 Disturbance power measurements with the absorbing clamp

The asymmetric RF current in a lead or on the outer surface of the screen of a screened cable will radiate energy to nearby or remote antennas depending on frequency, length and configuration of the connected cable. This is particularly important at VHF and UHF in which frequency ranges the external lead of the appliance has a length which is in the order of a half wavelength or longer.

The absorbing clamp is a device which gives measuring results in a good correspondence with the disturbance power that can be radiated from the external lead of the appliance.

Under this condition the disturbance power conducted through the mains lead and measured by the absorbing clamp is a good measure for the disturbance potential. If the dimensions of the source are not small compared with wavelength, a larger part of the disturbance's energy will be radiated directly and the absorbing clamp measurement is less reliable.

Because broadband disturbance is, in general, of less importance at frequencies above 300 MHz the absorbing clamp is recommended for the measurement of small appliances in the frequency range 30 MHz to 300 MHz.

5.3.2.4 Field-strength measurement

The field strength caused by disturbance sources is likely to be the most straightforward criterion for the interference potential of such a source, because it is more directly comparable with the wanted field strength at the antenna of a radio receiver particularly for remote coupling analysis.

A source radiates RF energy from its case or cabinet if a coupling path exists between internal noise source and external case or cabinet and if the dimensions of the case or cabinet are of the order of one wavelength. For practical reasons the electric component of the field is measured in the frequency range above 30 MHz (by means of dipole antennas) and the magnetic component of the field below 30 MHz (by means of loop antennas).

Field-strength measurements have a number of practical drawbacks. The influence of surrounding reflections should be eliminated which is usually met by using an open area test site (OATS). Such a test site introduces inaccuracies by variable reflections from the operator and from the ground (influence of moisture and season) and by interference from ambient transmitter fields. It also increases the work time due to poor weather and other climatic conditions. These drawbacks can be partly eliminated by use of anechoic rooms in the frequency range above 30 MHz.

Another drawback of field-strength measurements is the complex EUT radiation pattern which also depends on the test set-up. It therefore requires measurements in various directions and an accurately specified test set-up.

5.3.2.5 Radiation substitution measurements

In order to reduce the effect of surrounding reflections in field-strength measurements, the source under test is replaced by a radiator of specified characteristics and an adjustable output level (usually a dipole connected to a calibrated RF generator) to produce the same field strength under equal environmental conditions. The RFI of the appliance is expressed as the equivalent power radiated from the substitution radiator. This method is often used at frequencies above 1 GHz.

5.3.2.6 Disturbance power measurements with a reverberating chamber

The reverberating chamber method in essence is a radiation substitution method inside a screened cage and can be used in the frequency range above 300 MHz. By using rotating reflection plates (mode stirrers), the standing wave patterns inside the cage are continuously varied in such a way that the time averaged field strength is nearly independent of the position inside the cage. Therefore, the source under test and the substitution source need not be at exactly the same position and the calibration procedure for the radiated power is much simpler than in the normal substitution method.

5.3.2.7 Frequency considerations with respect to measuring methods

As indicated earlier, radiation of a device and its connected cables, and particularly of the mains cables, depend on the size of the device and of the cables compared with wavelength (frequency). The following table gives a general survey of the usefulness of various measuring methods with respect to the frequency bands (subdivided according to CISPR Recommendations). It should be noted that the frequency ranges are only for indication and the quoted valuation given for guidance.

Table 2 – Guidance survey of RFI measuring methods

Frequency MHz	Mains & signal port voltage	Asymmetrical current	Absorbing clamp	Field strength	Substitution radiation	Reverberation chamber
0,009 to 0,15	+	+	–	0	–	–
0,15 to 30	+	+	–	0	–	–
30 to 300	–	0	+	+	0	–
300 to 1 000	–	0	0	+	+	0
Above 1 000	–	–	–	+	+	0

Where

+ = to be recommended;

0 = usable;

– = not normally usable.

5.3.3 Disturbance signal waveforms and associated spectra

An important aspect is the RF spectrum which is associated with the signal waveform. As most radio services use relatively narrow frequency channels, the spectrum (frequency domain) is considered of major importance compared with the waveform (time domain). Therefore the following distinction is made.

Narrowband radio frequency interference (RFI) effects occur when the disturbance signal occupies a bandwidth smaller than the radio channel of interest or the measuring receiver. The disturbance spectrum may consist of a single frequency produced by a sinewave oscillator of medium or high RF power (i.e. by RF ISM equipment) or of low power (i.e. by electronic circuits, receiver oscillators). The oscillator could be modulated by the mains frequency. Oscillator frequencies can be generated over the entire usable frequency spectrum. The effect of narrowband disturbance is considered by CISPR over the frequency range 9 kHz to 18 GHz.

– Narrowband RFI from a disturbance with a rather broadband spectrum of discrete frequencies – Pulse waveforms derived from a digital clock oscillator contain discrete harmonic frequencies in a wide frequency range (broadband spectrum). For fundamental (clock) frequencies appreciably higher than the bandwidth of the radio channel, not more than one separate spectral line can coincide with the radio channel and such a spectral line is considered as narrowband RFI. Clock oscillators of computers are often dithered (i.e. are using frequency modulation on the clock).
– Continuous broadband RFI – Gaussian noise generated by gas discharge devices (lighting) produces continuously a flat spectrum during the operation of the device. Repetitive pulses produce a wide spectrum containing various discrete spectral lines. At repetition rates much lower than the radio channel bandwidth many spectral lines occur within the channel (broadband RFI), originating for example, from pulses derived from the mains frequency (commutator motors, semiconductor-controlled voltage regulators).

  The spectrum amplitude of repetitive pulses decreases above the transition frequency (the reciprocal of the pulse width) at 20 dB or 40 dB per decade, dependent on the pulse shape. Continuous broadband interference (as e.g. from spark ignition noise, arc welding equipment, etc.) is considered by CISPR over the frequency range 150 kHz to 1 GHz or higher.

  Broadband RFI may also be caused by disturbances or wanted signals from RF ISM equipment, as e.g. microwave ovens. There are two main types of microwave ovens depending on the power supply, those with a transformer and those with a switched mode power supply.
– Discontinuous broadband RFI – Switching operations by means of a hard contact (spark) generates short bursts of noise. Short-duration bursts of disturbances may cause less severe interference effects than long-duration bursts depending, however, on the average repetition rate of the bursts.

  For this reason CISPR allows a relaxation with respect to the limit of continuous disturbances for short bursts with a duration of less than 200 ms and with a repetition rate N of less than 30 clicks per minute. This relaxation factor equals 20 log 30/N. The frequency spectrum of such clicks is not essentially different from that of continuous broadband interference.

5.3.4 Characteristics of interfered radio services

The characteristics of radio services with respect to RFI are very important as well. In residential areas, radio services which can suffer from RFI are e.g. radio broadcasting, amateur radio, and (land) mobile radio communication. AM sound broadcasting operates at frequencies below 30 MHz and FM (stereo) sound broadcasting between 64 MHz and 108 MHz. TV broadcasting uses various channels in the range between 50 MHz and 900 MHz, the picture signal being modulated in AM-VSB and the sound signal in either AM or FM depending on the TV standard in use. Broadcasting also takes place in the bands between 11 GHz and 13 GHz. Amateur radio frequency bands are widely spread over the whole RF range and are allocated in the short wave up to the micro wave frequency bands.

Analogue sound and TV broadcasting are going to be replaced by broadcasting with digital modulation, like Digital Radio Mondiale (DRM) which is intended to replace the AM radio in the medium frequency (MF) and high frequency (HF) bands, Digital Audio Broadcasting (DAB or T-DAB) operated in the VHF and UHF bands, and Digital Video Broadcasting Terrestrial (DVB-T) operated in the UHF bands. These digital radio services require lower RF protection ratios (17 dB for DRM, 20 dB for DVB-T and 28 dB for DAB) than radio services with analogue modulation (where RF protection ratios of about 27 dB for AM, about 48 dB for FM and about 58 dB for TV are required). On the other hand, the transition between the interference level defined by the minimum wanted field strength minus the protection ratio and the disturbance which causes unacceptable interference is narrower than for analogue modulation.

In residential areas with private receiving antennas propagation of disturbances by radiation from noise sources and from mains cables is of major importance. Broadcast signals distributed through a cable (CATV) system are less vulnerable because of the more suitable location which can be selected for the common receiving antenna (i.e. for the head station), but if in such cases disturbances are coupled to such an antenna interference may be experienced by all subscribers connected to such a system.

Satellite broadcast signals in the 12 GHz range are generally not disturbed by broadband sources because of the limited frequency spectrum of broadband sources. The risk mainly depends upon the frequencies chosen for the first intermediate frequency band at the receiver.

The annoyance to the broadcast signal depends on the disturbance signal waveform. Narrowband and broadband sources produce different types of annoyance. Subjective tests have shown that for equivalent subjective assessment, narrowband disturbance should be of significantly lower amplitude than broadband disturbance (quasi-peak measured) in the 0,15 MHz to 30 MHz range. Assessment of disturbance to digital radio services is based on the bit-error probability (BEP). Tests have shown that the weighting of impulsive disturbance for its effect on digital radio communication services is generally different from the effect on radio communication services that use analogue modulation.

The influence of the repetition rate of rapid pulses in a broadcast channel is accounted for in the quasi-peak detector characteristic, the effect of low rate pulses (clicks) by the 20 log 30/N relaxation to the limit. In mobile communication (in older systems mainly narrowband FM, now replaced by digital mobile communication systems such as TDMA (e.g. GSM, PDC) and CDMA (e.g. cdmaONE, WCDMA, cdma2000 etc.), traffic noise sources (i.e. ignition interference) are the major source of RFI. In this respect the base station antenna is in a more favourable position with respect to RFI signals than the mobile antenna because of its higher location. Mobile antennas on the other hand change their position continuously and are therefore less vulnerable to stationary noise sources. For the calculation of emission limits in the frequency range above 1 GHz a detector with a weighting function appropriate for digitally modulated radio services may be considered.

Broadcasting and mobile services may be interfered by narrowband sources as well (RF ISM equipment, data processing equipment, receiver oscillators, etc.). The wanted radiated RF power from RF ISM equipment may be several orders higher than the level from broadband sources although the distances between those sources (industrial areas) and the victim receivers are normally longer. The disturbing energy, however, is mainly concentrated in a very narrow frequency band. For this reason a number of frequency bands is reserved for typical ISM applications.

In addition to broadcasting and mobile radio services, many different professional radio services such as fixed, aeronautical navigation, aeronautical mobile, maritime mobile, radiolocation, standard frequency and time, meteorological aids and radio astronomy services are in use. Other professional radio services (navigation, fixed services, satellite and microwave communication) are, in general, less vulnerable to radio interference because of the use of higher frequencies (greater than 1 000 MHz in which broadband interference is negligible), more favourable antenna locations, sophisticated systems (modulation, coding, antenna directivity) and technology (screening, filtering).

5.3.5 Operational aspects

Noise sources in residential areas mainly consist of mass-produced devices for domestic and sometimes for professional use. Such appliances are tested according to statistical procedures which implies that a restricted percentage of p per cent fulfils the limit with a limited confidence q per cent. Small batches reduce the figures p and q and CISPR recommends a value for both p and q of 80 per cent (80% - 80% rule). The rule is in general adequate to protect non-vital radio services like broadcast and most land mobile communication.

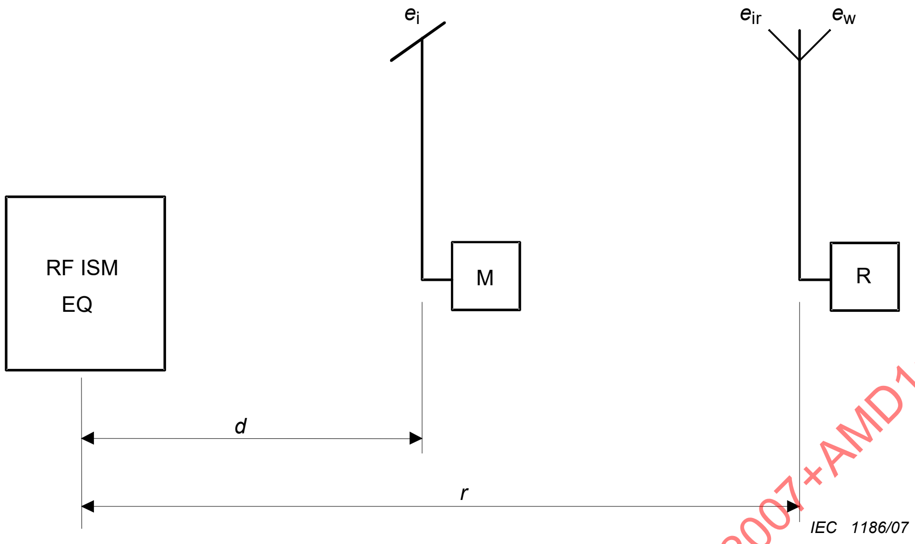
For critical or safety related radio services, however, a much higher degree of confidence is necessary. The actual annoyance in an interfered radio service does not only depend on the RFI field strength, but on the wanted signal level as well. The ratio of wanted-to-unwanted input level which procures a pre-defined and just still permissible minimum quality of performance of the receiver is called RF protection ratio R_p. This way, the wanted signal level needed to get at least the pre-defined minimum quality of performance depends on the natural and man-made noise level and which, in certain environments, may be much higher than the receiver's intrinsic noise level, particularly in the lower part of the radio frequency range.

In establishing limits for various types of noise sources it is important to strive for limits which have an equal effect on the radio services to be protected. The users of such a service are not interested in the type of source which causes RFI. Therefore disturbances from all types of sources should be suppressed as much as possible to an equal level of noise output.

5.3.6 Criteria for the determination of limits

5.3.6.1 Remote coupling

For remote coupling situations the field strength at a specified distance from the noise source is used as a characteristic for the interference potential of the source. The following model (see Figure 2) was developed to derive radiation limits for the case of in-band interference (i.e. interference appearing in the tuned channel of the victim receiver) caused by RF ISM equipment. For the relevant radio services in the allocated frequency bands the RF protection ratio is determined. In ITU documents, this protection ratio is given for disturbing radio services with the same modulation. The protection ratio for any other type of disturbance radiation, as e.g. for typical electromagnetic disturbances from other electrical or electronic apparatus, may be different.



Legend:

$$e_{ir} = e_w / r_p$$

e_{ir} = permissible interference field strength at the position of the antenna of the victim receiver R

e_w = wanted signal field strength to be protected at distance r at the position of the antenna of the victim receiver R (derived from ITU specifications)

r_p = protection ratio, i.e. minimum signal-to-interference ratio needed at the position of the antenna of the victim receiver to guarantee a certain quality of radio reception (derived from ITU specifications)

$$e_i = e_{ir}\, m_{ir}\, l_b\, p\, (r/d)^x$$

e_i = regulated disturbance field strength (CISPR limit) for sources of disturbance, i.e. other electric and electronic equipment and apparatus, at measuring distance d, i.e. at the position of the antenna of the measuring receiver M

m_{ir} = factor for polarization match between polarisation of e_{ir} and polarisation of the antenna of the victim receiver

l_b = screening factor of buildings or other obstacles

p = complex statistical probability factor, for considerations in this sub-clause defined to be 1, generally elaborated in 5.2, and in detail in 5.4. Further on in this report, separate components of this complex probability factor p may be denoted more generally as "influence factors".

x = wave propagation coefficient

NOTE The equations above are only valid for absolute physical quantities.

Figure 2 – Model for remote coupling situation derived disturbance field strength e_{ir} at receiving distance r

Expressed in logarithmic quantities, the permissible interference field strength E_{ir} at the antenna input of the victim receiver is the minimum (or nominal) wanted field strength E_w minus the protection ratio R_p:

$$E_{ir} = E_w - R_p$$

A minimum operational distance r between noise source and receiving antenna is specified and with the use of an estimated or empirical wave propagation factor x, the acceptable disturbance field strength E_i at a specified measuring distance d is calculated:

$$E_i = E_w - R_p + x \cdot 20\, \lg(r/d)$$

Next some additional factors, as e.g. the screening factor of buildings or other obstacles L_b and the factor for polarization match M_{ir}, should be introduced. Furthermore, a statistical factor P on the probability of actual interference under operational conditions should be used to adapt the calculated acceptable disturbance field strength E_i to normal conditions found in practice:

$$E_i = E_w - R_p + M_{ir} + L_b + P + x \cdot 20 \lg(r/d)$$

Such a probability factor P should take into account statistics of antenna directivity (in the direction of the wanted transmitter and of the interference source), distance variations, propagation variations, time coincidence, etc. (see also 5.4).

Adding the screening factor of buildings or other obstacles L_b, the factor for polarization match M_{ir}, and the decoupling attenuation via distance $L_o = x \cdot 20 \lg(r/d)$ into one new term L and setting the statistical probability factor P to 1, we eventually get:

$$E_i = E_w - R_p + L$$

where L actually represents all relaxations in the limits agreeable by CISPR in terms of EMC due to additional decoupling from the victim receiver for disturbances from electric and/or electronic equipment relative to the maximum permissible interference field strength E_{ir} at the antenna input of a victim receiver R, calculable from the radio parameters specified by ITU.

Accomplishing the above calculation by considerations to probability of interference, the final result of this procedure will be a calculated limit which is a good basis for an operational limit guaranteeing that the requirements of the protection ratio R_p are met on a statistical basis (x % of the actual cases). It should be noted that reliable statistical values for most of the parameters mentioned above are still not available to CISPR, and that in those cases rough estimations can be used only.

Moreover the interfering effect of signals in the out-of-band domain is more complex because of the selectivity and non-linearity characteristics of the receiver which can differ from case to case.

5.3.6.2 Close coupling

A simple model for close coupling situations is given in Figure 3. The noise source is considered as an RF generator with an e.m.f. U_s and an internal impedance Z_s for each mains connector/earth combination (for simplicity only one mains connector is shown). The mains network is connected between the noise source and the interfered receiver. The mains network offers a RF impedance Z_m to the source and transfers the energy from the noise source to the mains input port of the receiver.

In addition, part of the conducted RF energy is propagated as a magnetic and electric field. For the close coupling situations generally, near-field conditions exist (ratio electric/magnetic component undefined).

Two coupling paths exist between noise source and receiving antenna:

a) the path of disturbance conducted along the mains network, the mains supply circuit of the receiver and common ground of the receiver's electronic circuitry to the grounding point of the receivers RF input stage, and then via its antenna port input impedance to the antenna itself (path a1), together with the coupling between the mains supply circuit and other RF circuits inside the receiver (path a2). Paths a1 and a2 take effect only in case of mains powered receivers;

b) the path of disturbance conducted along and radiated by the mains network and coupled directly to the external or built-in antenna of the receiver. Path b exists for both, AC mains and battery powered receivers.

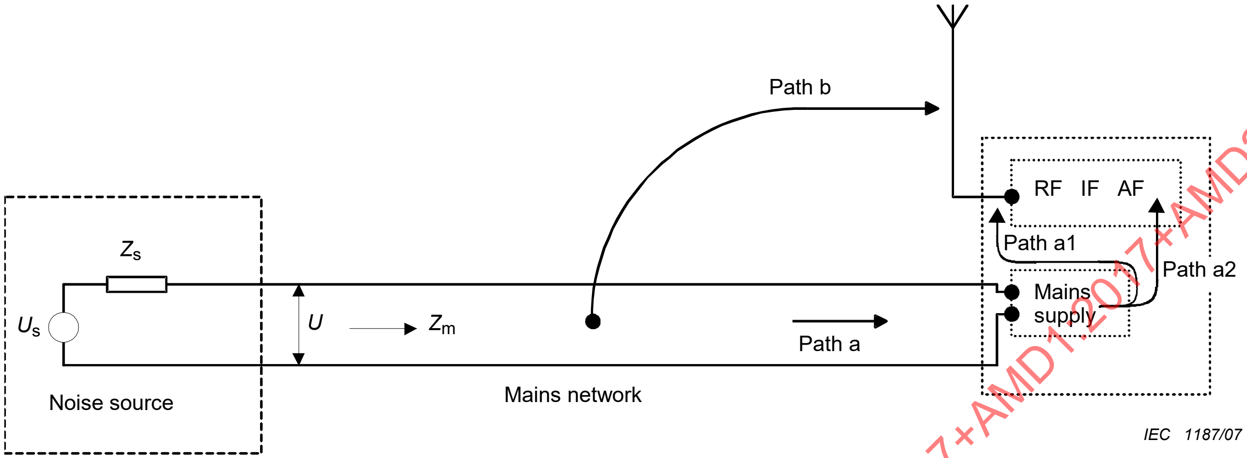


Figure 3 – Model for close coupling situations

In the case of external antennas, the RF power coupled through external path b) exceeds the power via path a1 and a2 appreciably. Moreover the internal coupling via a2 is determined by the mains immunity characteristics of the receiver, i.e. by the screening effectiveness of the internal IF and AF circuitry of the receiver, and it has been shown that it is not difficult to control the mains immunity factor of a receiver to an adequate level. This is however not the case for path a1 since the coupling always happens at the antenna port via the RF input impedance of the receiver's RF input stage. Therefore the attention is mainly focused on path b and path a1). Due to so far lacking investigation, for internal ferrite antennas no clear distinction can be made between paths a) and b). For build-in rod-antennas (used in the frequency range 1,7 to 30 MHz) clear distinction can be made between path a1 and path b. For calculation of CISPR limits in frequency bands up to 30 MHz used for AM radio broadcasting, it should be taken into account that ITU-R Rec. BS.703 specifies a receiver with built-in antennas (ferrite or telescopic rod antennas, depending on frequency range) as the reference receiver.

The modelling starts the same way as in the case of remote coupling. The acceptable disturbance field strength at the receiving antenna is calculated from the RF protection ratio and field strength to be protected in the relevant frequency bands. In the next step the coupling factor is measured from mains input (RF-voltage) to field strength at the antenna. It is, however, more usual to define a transfer factor as the ratio of the RF-voltage injected into the mains and the antenna output voltage (for a specified antenna). This factor is known as the mains decoupling factor. Because of the wide spread in actual situations, extensive statistical material is needed to found a basis for disturbance limits derived from mains decoupling factors. CISPR Report No. 31 (“Values of mains decoupling factor in the range 0,1 MHz to 200 MHz”, see Annex A) shows median values, standard deviations and minimum values of the mains decoupling factor. The effect of coupling path a) is described in 5.5.2.1, whereas the effect of coupling path b) for mains and telecommunication line coupling is described in 5.5.2.2.

Another statistical aspect in the calculation of limits in this concept is the variation of the RF-impedance at the mains input. Although individual decoupling factors are determined by the measured voltage, independent of the actual mains impedance, the interference limit shall be defined for a fixed simulated impedance (artificial mains network impedance), in order to get reproducible measuring results during CISPR disturbance measurements at standardized test sites. In practice, the RF-load impedance of the mains network varies from location to location and from time to time. This aspect should be considered in deriving a limit from mains decoupling measuring data.

In general, close coupling of an appliance connected to the mains can sufficiently be evaluated by measurement of the disturbance voltage at its mains port. For a given mains network, only one unique set of limits for conducted emissions at the mains port of connected appliances should be used. As a consequence, the stricter limit should apply, if for the mains port two different limits result from the limit calculation for paths a) and b), respectively.

5.3.6.3 General

The derivation of limits from a hypothetical model requires the introduction of various experimental data in such a model. As these data, as pointed out earlier, are based on statistical measurements under different actual circumstances, the usefulness of such data for general application is often debatable.

On the other hand, the implementation of suppression measures should be considered on physical, operational, manufacturing and not in the least on economic aspects. Therefore the model should be used as a worthwhile starting point but the final limit value is often the result of an agreement between parties involved after extensive considerations and negotiations.

5.4 A mathematical basis for the calculation of CISPR limits

This subclause contains the basic mathematical model that can be used for calculation of CISPR limits. The start-up point is the supposition that there is an identifiable probability inequality to be satisfied, and the assumption that the parameters obey a log-normal distribution.

5.4.1 Generation of EM disturbances (source of disturbance)

From the mathematical point of view any limit must be calculated with the provision that the inequality

$$z = x/y \geq 1 \tag{6}$$

is satisfied with some probability α.

If in Equation (6) x and y are independent random values of quantities (e.g. of disturbance signals, immunity, etc., which influence the radio reception quality) with log-normal distribution, then $10 \lg (x) = X$ (dB) and $10 \lg (y) = Y$ (dB) will have normal distribution with parameters μ_x (dB), μ_y (dB), σ_x (dB) and σ_y (dB). Hence $X - Y = Z$ (dB) will have a normal distribution with the parameters

$$\mu_Z = \mu_x - \mu_y \qquad \text{and} \qquad \sigma_Z = \left[\sigma_x^2 + \sigma_y^2\right]^{1/2}$$

In this case

$$P\left(\frac{x}{y} \geq 1\right) = P\,(Z \geq 0) = P\left(\frac{Z-\mu_Z}{\sigma_Z} \geq \frac{-\mu_Z}{\sigma_Z}\right) = P\left(\frac{Z-\mu_Z}{\sigma_Z} \leq \frac{\mu_Z}{\sigma_Z}\right) = F\left(\frac{\mu_Z}{\sigma_Z}\right) \tag{7}$$

where F denotes the normal $N(0,1)$ distribution function (see [1][4]).

The reliability of obtaining a pre-set level α for the quality of a radio service is expressed by:

$$\alpha = P\left(\frac{x}{y} \geq 1\right), \qquad \text{therefore:} \qquad \frac{\mu_Z}{\sigma_Z} = F^{-1}(\alpha) = t_\alpha \tag{7a}$$

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

where t_α is the α-quantile of the centralized normal distribution (see [1], page 180).

Solving Equation (7a) relative to μ_x or μ_y, we get:

$$\mu_x = \mu_y + t_\alpha \sigma_z \quad (8)$$

$$\mu_y = \mu_x - t_\alpha \sigma_z \quad (9)$$

The CISPR limit L is determined for some quantile t_β in distribution of probabilities of the value x or y for which limits are established, in such a way that the following equalities are true:

$$\beta = P(X \geq L_X) \quad \text{i.e.} \quad L_x = \mu_x - t_\beta \sigma_x \quad (10)$$

$$\beta = P(Y \leq L_Y) \quad \text{i.e.} \quad L_y = \mu_y + t_\beta \sigma_y \quad (11)$$

where t_β is the β-quantile of the centralized normal distribution (see [2], page 84 example 2.17).

Substituting Equation (8) into Equation (10) and Equation (9) into Equation (11)

$$L_x = \mu_y + t_\alpha \sigma_z - t_\beta \sigma_x \quad (12)$$

$$L_y = \mu_x - t_\alpha \sigma_z + t_\beta \sigma_y \quad (13)$$

one is enabled to calculate limits for different parameters, which ascertain the radio reception quality.

5.4.2 Immunity from EM disturbances (victim receiver)

Inequality (6) has the form:

$$x/y \geq 1$$

where

x is a parameter of receptor immunity;

y is a parameter of electromagnetic environment in respect to which the immunity limit is established.

If the values X (dB) and Y (dB) are satisfactorily approximated by normal distributions with parameters μ_x, σ_x, μ_y, σ_y then

$$\sigma_z = \left[\sigma_x^2 + \sigma_y^2\right]^{1/2} \quad (14)$$

In this case, according to Equation (12), the equation for the calculation of receptor immunity limits has the following form:

$$L_x = \mu_y + t_\alpha \left[\sigma_x^2 + \sigma_y^2\right]^{1/2} - t_\beta \sigma_x \quad (15)$$

5.5 Application of the mathematical basis

5.5.1 Radiation coupling

NOTE This describes the effect of remote coupling as in 5.3.6.1.

This subclause adapts the basic model for the case where it is wished to protect a radio service when there is radiation coupling from the source of EM disturbance to the antenna of the radio receiver. The actual signal-to-disturbance ratio R can be expressed in terms of the wanted signal, the disturbing signal, the propagation losses and the antenna gain, as follows:

$$R = E_w(\mu_w;\sigma_w) + G_w(\mu_{Gw};\sigma_{Gw})$$

$$- [E_i(\mu_i;\sigma_i) + G_i(\mu_{Gi};\sigma_{Gi}) - L_o(\mu_{Lo};\sigma_{Lo}) - L_b(\mu_{Lb};\sigma_{Lb}) + M_{ir}(\mu_m;\sigma_m)] \quad \text{dB} \qquad (16)$$

where

E_w is the actual field strength of the wanted signal at the position of the radio receiver's antenna as a function of its mean value (μ_w) and the standard deviation (σ_w);

E_i is the field strength of the disturbance signal at the measurement distance d on a test site as a function of its mean value (μ_i) and standard deviation (σ_i);

G_w is the actual value of the radio receiver's antenna gain for the wanted signal as a function of its mean value (μ_{Gw}) and standard deviation (σ_{Gw});

G_i is the actual value of the radio receiver's antenna gain for the disturbance signal as a function of its mean value (μ_{Gi}) and standard deviation (σ_{Gi});

L_o is the actual value of the factor which takes account of the attenuation of the disturbance field strength on its propagation path to the position of the radio receiver's antenna when it is propagated through free space without obstacles as a function of its mean value (μ_{Lo}) and standard deviation (σ_{Lo}) in relation to the measurement distance d on the test site:

$$L_o = x \cdot 20 \lg (r/d);$$

L_b is the actual value of the factor which takes account of the attenuation of the disturbance field strength caused by obstacles in its propagation path as a function of its mean value (μ_{Lb}) and standard deviation (σ_{Lb}) relative to the value for free-space propagation.

M_{ir} is the actual value of the factor for polarization match between the disturbance field strength E_{ir} and the receiving antenna of the victim receiver as a function of its mean value (μ_m) and standard deviation (σ_m). The absolute value m_{ir} equals 1, when the receiving antenna polarization matches the polarization of E_{ir} and becomes less than 1 in all other cases. Since M_{ir} and the related mean value μ_m are used in logarithmic terms their quantities are equal to or smaller than 0 dB and thus always have a negative sign.

If, as assumed, all variables on the right-hand side of Equation (16) obey a normal distribution law, then the distribution factors are related as follows:

$$\mu_R = \mu_w + \mu_{Gw} - \mu_i - \mu_{Gi} + \mu_{Lo} + \mu_{Lb} - \mu_m \quad \text{dB} \qquad (17)$$

$$\sigma_R^2 = \sigma_w^2 + \sigma_{Gw}^2 + \sigma_i^2 + \sigma_{Gi}^2 + \sigma_{Lo}^2 + \sigma_{Lb}^2 + \sigma_m^2 \quad (\text{dB})^2 \qquad (18)$$

With a normal distribution law the reliability of obtaining the pre-set quality of service can be expressed by the following function of the normal probability distribution:

$$P(R > R_p) = F[-(R_p - \mu_R) / \sigma_R] = \alpha \qquad (19)$$

therefore:

$$\mu_R = R_p + t_\alpha \sigma_R \qquad (20)$$

where $t_\alpha = F^{-1}(\alpha)$

By combining Equations (17), (18) and (20) an expression is obtained for the permissible mean value (μ_i) of the disturbance field strength at a pre-set distance from the source of disturbance:

$$\mu_i = \mu_w + \mu_{Gw} - \mu_{Gi} + \mu_{Lo} + \mu_{Lb} - \mu_m - R_p$$
$$- t_\alpha \left[\sigma_w^2 + \sigma_{Gw}^2 + \sigma_i^2 + \sigma_{Gi}^2 + \sigma_{Lo}^2 + \sigma_{Lb}^2 + \sigma_m^2\right]^{1/2} \quad (21)$$

The mean value of the disturbance shall be below the limit, and may be specified as follows:

$$\beta = P(E_i \le E_{Limit}) \quad \text{i.e.} \quad E_{Limit} = \mu_i + t_\beta \sigma_i \quad (22)$$

where

E_{Limit} is the limit for the disturbance measured on a test site at a specified distance; and

t_β is the β-quantile of the centralized distribution function which corresponds to a probability level of compliance with the limits.

The free space attenuation factor (μ_{Lo}) can be evaluated from

$$\mu_{Lo} = x \cdot 20 \lg (r/d) \quad (23)$$

where

r is an average distance between the disturbance source and the receiving antenna;

d is the pre-set or specified measurement distance on the test site;

x is the exponent which determines the actual free-space attenuation rate.

Combining Equations (21), (22) and (23) the limit is given by:

$$E_{Limit} = \mu_w + \mu_{Gw} - \mu_{Gi} + x \cdot 20 \lg (r/d) + \mu_{Lb} - \mu_m - R_p + t_\beta \sigma_i$$
$$- t_\alpha \left[\sigma_w^2 + \sigma_{Gw}^2 + \sigma_i^2 + \sigma_{Gi}^2 + \sigma_{Lo}^2 + \sigma_{Lb}^2 + \sigma_m^2\right]^{1/2} \quad (24)$$

CISPR Recommendation 46/1 (see CISPR 16-4-3) specifies that 80 % of series-produced equipment should meet the disturbance limit, and that the testing should be such that there is 80 % confidence that this is so. For these conditions t_β assumes a value of 0,84.

5.5.2 Wire-line coupling

5.5.2.1 Mains coupling using the mains decoupling factor

NOTE This describes the effect of coupling path a) as in 5.3.6.2.

The required quality of radio communications is considered to be fulfilled, if the probability, that the actual signal-to-disturbance ratio R is greater than the minimum acceptable value R_p, exceeds a specified value. That is

$$P(R > R_p) \ge \alpha \quad (25)$$

where

R is the actual signal-to-disturbance ratio at the receiver's antenna port;

R_p is the minimum acceptable value of the signal-to-disturbance ratio at the receiver's antenna port;

α is a specified value representing the reliability of radio communications.

The relationship between the actual signal-to-disturbance ratio and generated electromagnetic disturbance is:

$$R = U_w - U_{ir\,=\,Uw} - U_i + K \quad \text{dB} \tag{26}$$

where

U_w is an effective value of wanted signal at the receiver's antenna port or feeding point;

U_{ir} is the permissible effective disturbance level at the receiver's antenna port or feeding point;

U_i is a value of a specified component of the electromagnetic disturbance (as e.g. voltage, current, power, etc.) measured at the mains port of the disturbance source in a specified way using specified equipment (i.e. a quasi-peak detector);

K is a decoupling factor defined as a ratio of U_i to an effective value of electromagnetic disturbance signal U_{ir} at the receiver's antenna port or feeding point.

For the situations where the disturbance is coupled predominantly by conduction (frequencies below 30 MHz):

$$K = K_m + I \quad \text{dB} \tag{27}$$

where

K_m is the mains decoupling factor relating U_i measured at the source (by an artificial mains network) to the value of disturbance at the mains input to the receiving installation;

I is the mains immunity factor relating the value of disturbance at the mains input to an equivalent disturbance which, if applied at the antenna port or feeding point of the receiving installation, would produce the same effect.

NOTE Such a receiving installation may comprise a usual broadcast radio receiver with built-in antenna, or a professional radio receiver connected to an external outdoor antenna as well.

It has been established experimentally that probability distributions of U_w (dB), U_i (dB) and K for arbitrarily selected disturbance sources, radio receiving installations and distances between them is well approximated by a normal distribution law.

A limit for electromagnetic disturbances applying to the mains port of the disturbance source is established for a definite quantile $U_i(p)$ in the probability distribution of U_i. A permissible value L for $U_i(p)$ is selected in such a way that at $U_i(p) = L$, a reliability of guaranteeing a radio reception which has a quality $R \geq R_p$ would be equal to the specified value α:

$$U_{Limit} = L_{pr}(U_i) = \mu_{Uw} + \mu_k - R_p + t_\beta \sigma_{Ui} - t_\alpha [\sigma^2_{U_w} + \sigma^2_{U_i} + \sigma^2_k]^{1/2} \tag{28}$$

μ and σ^2 are expectations/variances of corresponding components; $t_\alpha = F^{-1}(\alpha)$, $t_\beta = F^{-1}(\beta)$ are arguments of a standard normal distribution function (with zero mean and variance of unity) which is equal to t_α and t_β, respectively.

For series-produced articles CISPR recommends that β = 0,8; then t_β = 0,84. A value of α is selected between 0,8 and 0,99, depending on the type of a radio network (radio broadcasting, air navigation, *et al*). When α = 0,95, then t_α = 1,64.

It has been found experimentally that σ_k is the most significant factor. A change in the value of σ_k with an equivalent change in the limit for U_i results in no variation from the specified quality and reliability of radio performance. Therefore, limits are calculated for equipment located in similar conditions relative to radio receiving installations of a given radio network. For instance, in order to protect a broadcast reception in dwelling houses, it is enough to consider two groups only:

– equipment located in dwelling houses or connected to their supply mains;
– equipment located outside dwelling houses.

The second group, on the basis of economic considerations and separation distance, is divided into the following subgroups: power lines; electric transport; motor vehicles; industrial equipment located in an assigned territory; etc.

5.5.2.2 Mains and telecommunication line coupling by radiation from a network

NOTE This describes the effect of coupling path b) described in 5.3.6.2

This model assumes:

– the injection of symmetric (differential mode), asymmetric (common mode) and combinations thereof (i.e. unsymmetrical) voltages/currents into the network and the conversion of symmetric and symmetric components of unsymmetrical voltages/currents into effective asymmetric (common mode) voltages/currents due to the properties of the complete installation (network including connected apparatus);
– the attenuation of asymmetric disturbances between source and victim receiver location along the distribution network
– the generation of a magnetic (near-)field by asymmetric (common mode) disturbance currents and the coupling of this field into ferrite antennas of broadcast radio receivers in the long and medium frequency ranges,
– the generation of an electric (near-)field by asymmetric (common mode) disturbance voltages and the coupling of this field into telescopic rod antennas of radio receivers in the higher frequency range, and
– in the frequency range above about 10 MHz the generation of an electromagnetic field by the asymmetric (common mode) disturbance power via a radiating half-wave dipole and the coupling of this field into the antenna of radio receivers operating in this frequency range.

Similar to 5.5.1 we define the following quantities (with log-normal distribution):

E_w is the actual field strength of the wanted signal at the position of the radio receiver's antenna as a function of its mean value (μ_w) and standard deviation (σ_w);

E_{ir} is the actual field strength of the disturbance signal (generated by the asymmetric disturbance current $I_{i,}$ on a cable of the network ($E_{ir} = Z_0\, H_{ir}$), or generated by the asymmetric disturbance voltage $U_{i,}$ or generated by the asymmetric disturbance power P_i) at the position of the receiving antenna as a function of its mean value (μ_i) and standard deviation (σ_i);

M_{ir} is the actual value of the factor for polarization match between the disturbance field strength E_{ir} and the receiving antenna of the victim receiver as a function of its mean value (μ_m) and standard deviation (σ_m). The absolute value m_{ir} equals 1, when the receiving antenna polarization matches the polarization of E_{ir} and becomes less than 1 in all other cases. Since M_{ir} and the related mean value μ_m are used in logarithmic terms their quantities are equal to or smaller than 0 dB and thus always have a negative sign.

C is the value of the conversion factor $C_I = E_{ir}/I_i$ or $C_U = E_{ir}/U_i$ or $C_P = E_{ir}/P_i$ as a function of its mean value (μ_c) and standard deviation (σ_c). C_I and C_U can be estimated, in a first approach, by use of the law of Biot-Savart, if for that estimation the impedance Z at the point of interest is taken into account, and C_P can be estimated by the field strength expected from a tuned half-wave dipole substituting a certain cable length at the given location. Since C is always smaller than 1, its logarithmic quantities become negative;

A is the value of the attenuation between I_i' (resp. U_i' or P_i') at the source location and I_i (or U_i, or P_i, respectively) at the receiver location as a function of its mean value (μ_a) and standard deviation (σ_a);

Z is the value of the (frequency-dependant) impedance between the effective asymmetric disturbance voltage U_i and the effective asymmetric disturbance current I_i at the same (e.g. source) location as a function of its mean value (μ_z) and standard deviation (σ_z);

U_i' is the value of the effective asymmetric voltage at the source location as function of its mean value (μ_u) and standard deviation (σ_u);

P_i is determined by the ratio of U_i^2/Z or $I_i^2 \cdot Z$ at the points of interest;

Then (written as logarithmic quantities) the actual signal-to-disturbance ratio R is

$$R = E_w\ (\mu_w;\sigma_w) - [E_{ir}(\mu_{ir};\sigma_{ir}) + M_{ir}(\mu_m;\sigma_m)] \quad (29)$$

with

$$E_{ir}\ (\mu_{ir};\sigma_{ir}) = U_i'\ (\mu_u;\sigma_u) - Z(\mu_z;\sigma_z) - A(\mu_a;\sigma_a) + C(\mu_c;\sigma_c) \quad (30)$$

and the permissible mean value of the disturbance field strength will be obtained using:

$$\mu_{ir} = \mu_w - \mu_m - R_p - t_\alpha(\sigma_w^2 + \sigma_m^2 + \sigma_{ir}^2)^{1/2} \quad (31)$$

μ_{ir} can also be expressed as μ_{ir}/dB(μV/m) = μ_u/dB(μV) – μ_z/dB(Ω) – μ_a/dB + μ_c/dB(Ω/m), and σ_{ir} can be expressed as $\sigma_{ir}^2 = \sigma_u^2 + \sigma_z^2 + \sigma_a^2 + \sigma_c^2$ (units of σ in dB).

Therefore the permissible mean value of the asymmetrical (common mode) disturbance voltage can be defined as

$$\mu_u = \mu_w - \mu_m - R_p + \mu_z + \mu_a - \mu_c - t_\alpha(\sigma_w^2 + \sigma_m^2 + \sigma_u^2 + \sigma_z^2 + \sigma_a^2 + \sigma_c^2)^{1/2} \quad (32)$$

Taking into account Equation (22), the limit U_{Limit} becomes

$$U_{Limit} = \mu_w - \mu_m - R_p + \mu_z + \mu_a - \mu_c + t_\beta\sigma_u - t_\alpha(\sigma_w^2 + \sigma_m^2 + \sigma_u^2 + \sigma_z^2 + \sigma_a^2 + \sigma_c^2)^{1/2} \quad (32a)$$

Respectively, in the frequency range above 10 MHz, the disturbance field strength can be estimated by

$$E_{ir} = 7/d \cdot \sqrt{P_i} \quad (33)$$

That means that

$$\mu_{ir}/\text{dB}(\mu\text{V/m}) = 20\ \lg(7/d)/\text{dB}(\Omega^{½}/\text{m}) + \mu_u/\text{dB}(\mu\text{V}) - 0{,}5\mu_z/\text{dB}(\Omega^{½}) - \mu_a/\text{dB}$$

For d = 3 m, the first term is 7,4 dB

$$\mu_u = (\mu_w - \mu_m - R_p + \mu_a + 0{,}5\mu_z - 7{,}4) - t_\alpha(\sigma_w^2 + \sigma_m^2 + \sigma_u^2 + \sigma_z^2/4 + \sigma_a^2)^{1/2} \quad (34)$$

Taking into account Equation (22), the limit U_{Limit} becomes

$$U_{Limit} = (\mu_w - \mu_m - R_p + \mu_a + 0{,}5\mu_z - 7{,}4) + t_\beta\sigma_u - t_\alpha(\sigma_w^2 + \sigma_m^2 + \sigma_u^2 + \sigma_z^2/4 + \sigma_a^2)^{1/2} \quad (34a)$$

Example for the AM frequency range:

According to ITU Recommendation BS.703, the minimum receive field strength μ_w (σ_w set to 0) should be

- for Band 5 (LF): 66 dB(μV/m)
- for Band 6 (MF): 60 dB(μV/m)
- for Band 7 (HF): 40 dB(μV/m) (for DSB and SSB modulation)

whereas the other mean values have been assumed as

- RF protection ratio: R_p = 27 dB
- Polarization match: μ_m = – 6 dB, and σ_m = 4 dB
- Impedance: μ_z = 34 dB(Ω) (i.e. Z = 50 Ω), and σ_z = 4 dB
- Attenuation: μ_a = 10 dB, σ_a = 5 dB
- Conversion factor: μ_c = – 27 dB(Ω/m), if the receiver is assumed to operate at a distance of 3 m from a cable of the network, with σ_c = 3 dB.
- Standard deviation of the disturbance voltage: σ_u = 15 dB (see Figure 4 below)

Applying Equation (32a) to the MF range, with t_α = 0,84 and t_β = 0,84, the permissible mean value of the asymmetric disturbance voltage becomes 41,67 dB(μV) and the calculated limit becomes 54,27 dB(μV).

Using Equation (34a) for the range at 30 MHz we get the permissible disturbance mean voltage as 15,1 dB(μV) and the calculated limit becomes 27,7 dB(μV). This value is calculated under the assumption of far field conditions.

Guidance for field-strength measurements:

In the long and medium wave frequency bands, the disturbance field strength should be measured with a loop antenna, whereas in the short wave frequency bands, the disturbance field strength should be measured with a highly balanced shortened dipole antenna (it is not possible to use rod antennas in buildings since the counterpoise is floating).

Example of a measurement result:

It is normally not possible to model complicated network structures, like e.g. AC mains networks. It is therefore necessary to make a sufficient number of measurements with subsequent statistical evaluation of the results. For that purpose it is advisable to feed a certain (common or differential mode) power into the network and to measure the maxima of the magnetic (or electric) field strength at defined distances from the feed point along the network and at certain distances (e.g. 3 m, which may be difficult inside buildings) from the network lines, at a number of points which is sufficient for the determination of valid statistical parameters.

The measurement results presented in Figure 4 have been obtained in a study executed in Dresden commissioned by the German administration, see [3].

All data for the conversion factor were obtained by measuring the magnetic component of the disturbance field strength H_k in a building with 4 feed points using 26 different field-strength measurement locations. For the standard deviation s(H_k), the right hand scale of Figure 4 applies.

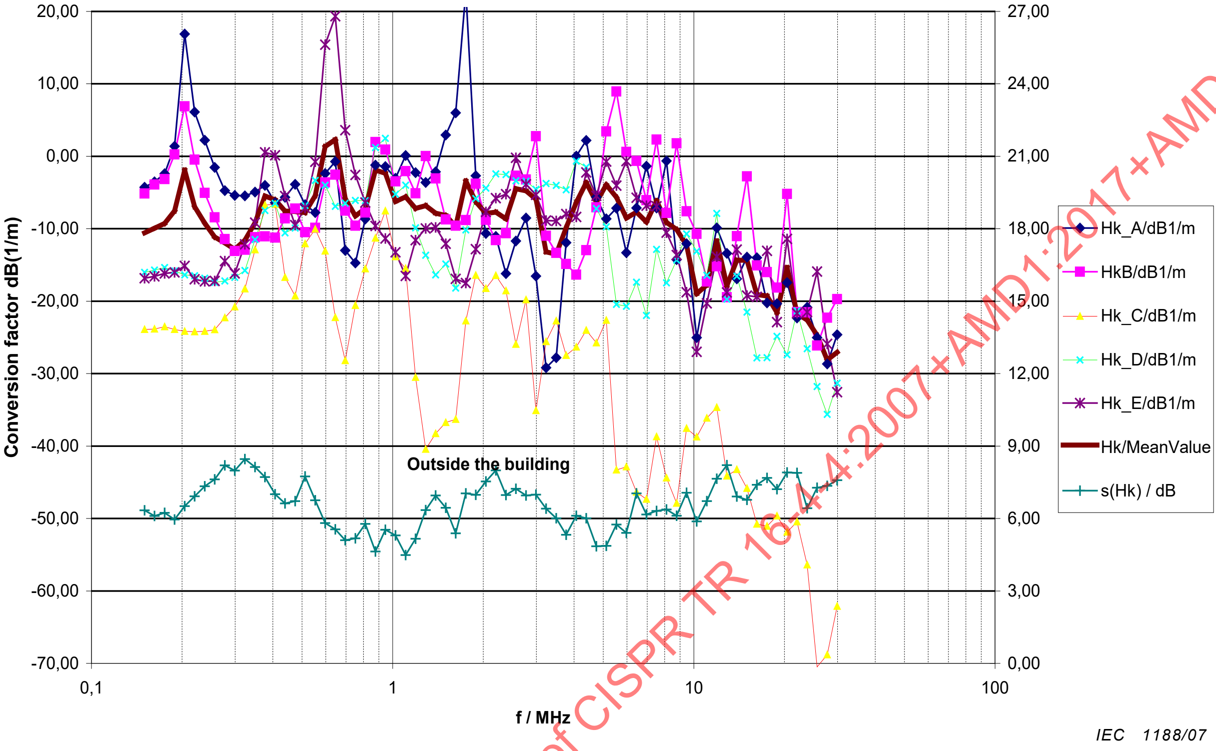


Figure 4 – Example of conversion factors – field strength / common-mode voltage (in dB) – at feed point, found in practice

The conversion factor (field strength divided by common-mode voltage, in dB) helps to determine limits for the common-mode voltage for a given scenario (with e.g. the radio service operated at a certain distance from the network, and assuming a specified longitudinal conversion loss (LCL) for the network).

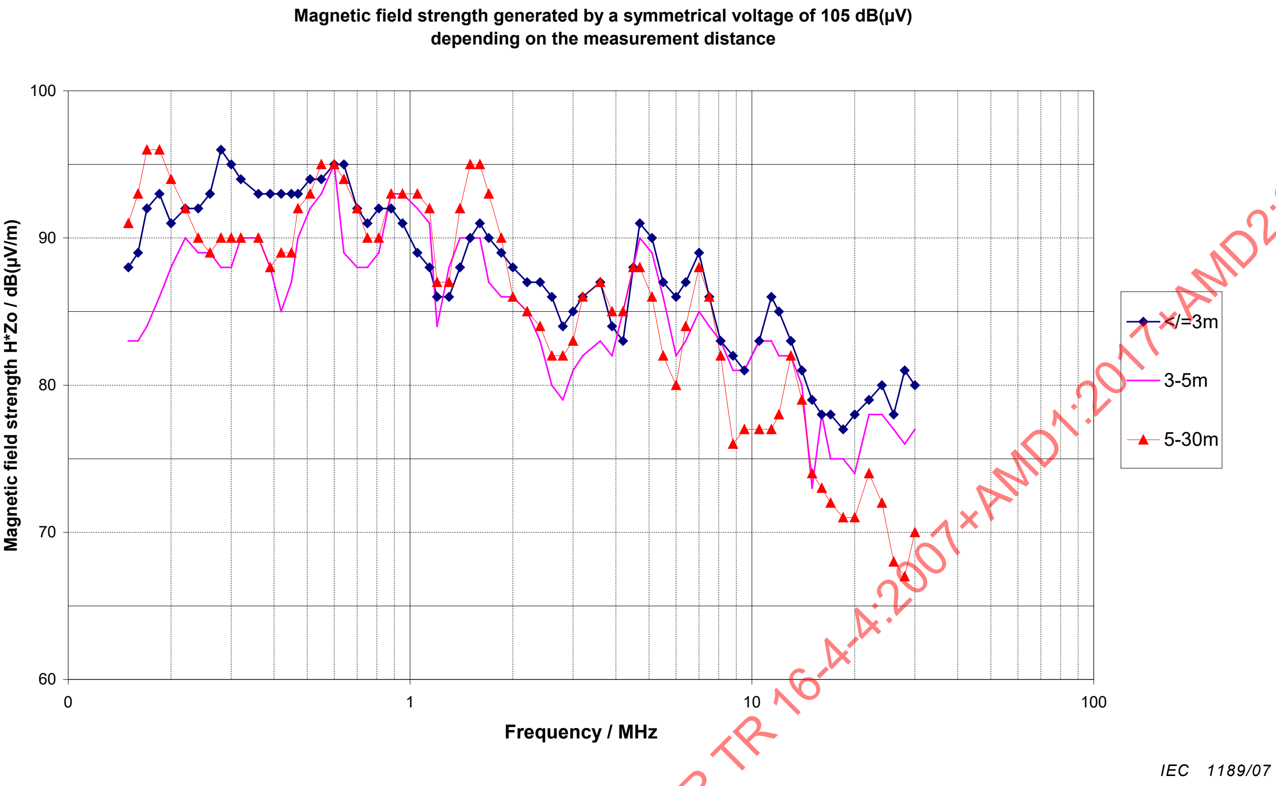


Figure 5 – Example of conversion factors – field strength generated by differential-mode voltage – at feed point, found in practice

Other conversion factors have been obtained feeding a certain differential-mode power into power-line networks (see Figure 5). The comparison of the conversion factors for differential and for common-mode power will show the effective differential mode rejection of the network.

Figure 5 shows an example of results from measurements of the magnetic disturbance field strength (H-field converted to E-field using the free-space wave propagation impedance Z_0) generated by a differential-mode voltage injected into a LV AC mains network between life and neutral lines. From this measurement result, the conversion factor from differential-mode voltage to field strength can be obtained. (The example indicates the 90% value of the field strength, i.e. the field strength not exceeded by 90% of the values. The results base on 48 measurement points within a distance of up to 3 m, 57 measurement points between 3 and 5 m and 87 measurement points between 5 and 30 m.)

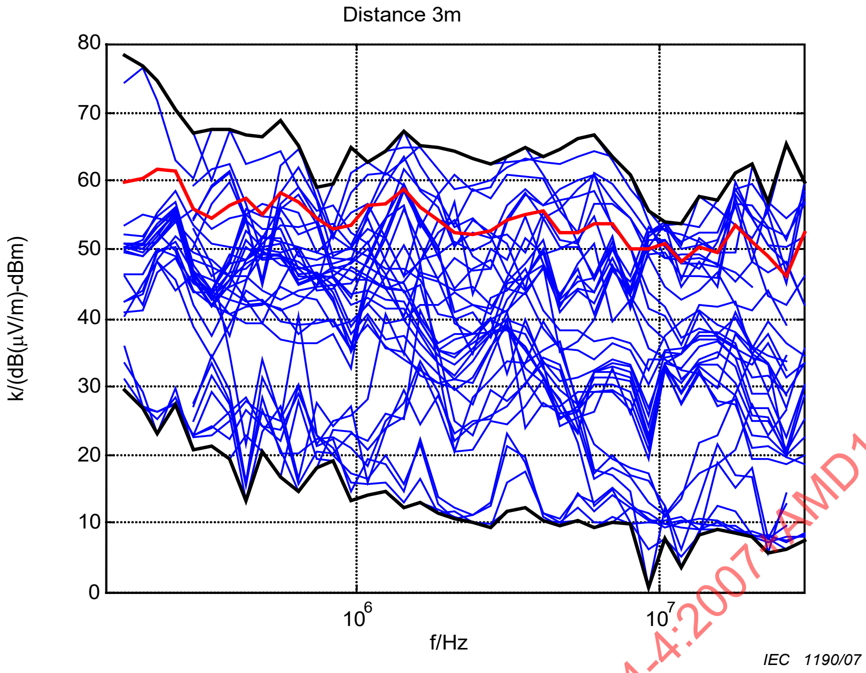


Figure 6 – Example of conversion factors – field strength generated by differential-mode voltage – outside buildings and electrical substations, found in practice

Figure 6 shows an example of results of measurements of the magnetic disturbance field strength (H-field converted to E-field using the free-space wave propagation impedance Z_0) generated by a differential-mode voltage of 108 dBµV (9 kHz) injected into a three phase LV AC mains network between two phase lines. The red line indicates the 80% field strength, i.e. at least 80% of all measurement results are lower than the red line value, with a confidence of 80%. The results base on measurements at 160 points within a distance of 3 m from buildings and electricity substations. Notice that this is not always identical with the distance to the cables of the mains grid.

Figure 7 shows an example of results of measurements of the magnetic disturbance field strength (H-field converted to E-field using the free-space wave propagation impedance Z_0) generated by a differential-mode voltage of 108 dBµV (9 kHz) injected into a LV AC mains network between phase and neutral lines. The red line indicates the 80% field strength, i.e. at least 80% of all measurement results are lower than the red line value, with a confidence of 80%. The results base on measurements on 67 points within a distance of up to 3 m from the cables in the middle of normal rooms inside buildings.

NOTE Figures 6 and 7 show the coupling factor *k* as a function of frequency. It is defined as the transfer function between the forward power injected into the LV AC mains network and the produced field strength. Using *k*, the upper limit value of the wanted signal power may be determined which may be injected into a telecommunication network without exceeding a given disturbance limit.

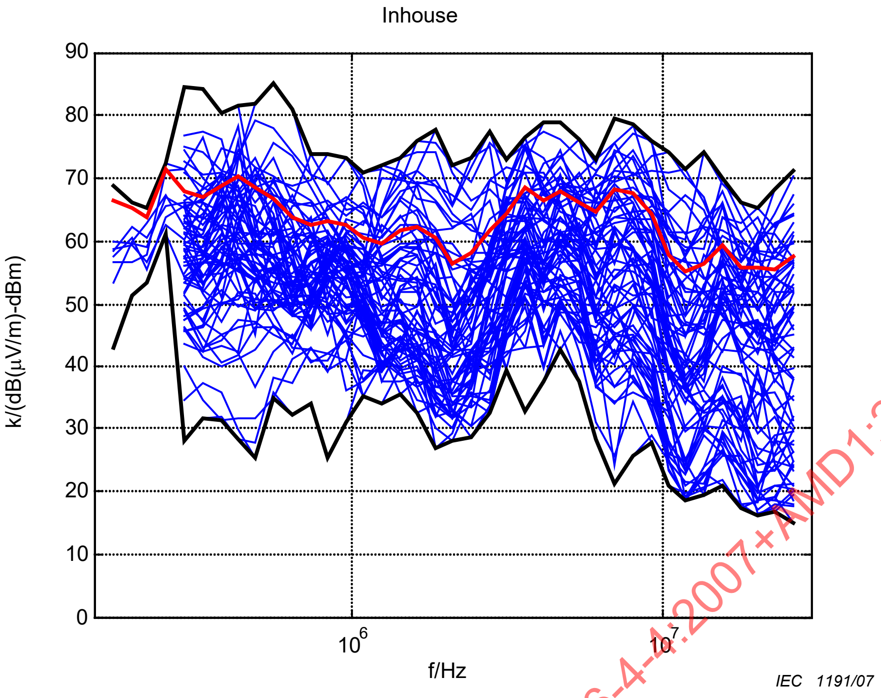


Figure 7 – Example of conversion factors – field strength generated by differential-mode voltage – inside buildings, found in practice

5.6 Another suitable method for equipment in the frequency range 150 kHz to 1 GHz

5.6.1 Introduction

The purpose of this subclause is to review studies made for the derivation of CISPR limits for the protection of telecommunications from interference from RF ISM equipment and to conclude from these a recommended method which meets the objectives of CISPR and ITU. The model deals only with radiation which occurs outside the wanted frequency bands designated by ITU for use by industrial, scientific, and medical (ISM) applications, i.e. outside the ISM bands.

5.6.2 Derivation of limits

The full range of parameters to be taken into account in the derivation of limits is shown in Table 3 together with the major radio services requiring protection.

5.6.2.1 Protection of communication services

The wanted field strength to be protected, the protection ratio required for the different types of radio services, the distance from the source at which protection is necessary, and the attenuation law to be used in the calculation are important. These are matters in which ITU support is essential.

5.6.2.2 Proposed model for use in calculating disturbance limits

The factors that have traditionally been included in models for predicting interference from radio-frequency sources are listed in columns 1 to 10 of Table 3. By assigning appropriate values to each parameter, for example, field strength to be protected, protection ratio, etc., worst-case limits for protecting the various communication services from interference from a certain type of equipment may be determined. However, a model which is based on worst-case parameters is both technically and economically unrealistic since it ignores the fact that there have been very few instances of interference attributed to the distinct type of equipment actually considered. It is therefore critical that the experience in this subject should be taken into account. Thus, the benefits of worldwide experience in this subject can be included although it is recognized that the probability can only be a qualified estimate at present, because so many complex factors are involved as shown in 5.6.2.3. Determination of numerical values of the probability for the various radio services is urgently required and studies are being undertaken in several countries.

5.6.2.3 Probability factors

Probability of coincidence of adverse factors:

~~$P = P_1 \times P_2 \times P_3 \times P_4 \times P_5 \times P_6 \times P_7 \times P_8 \times P_9 \times P_{10}$~~

$$P = P_1 \times P_2 \times P_3 \times P_4 \times P_5 \times P_6 \times P_7 \times P_8 \times P_9 \times P_{10} \quad (35)$$

where

- P_1 is the probability that the major lobe of the radiation is in the direction of the victim receiver;
- P_2 is the probability of directional receiving aerials having maximum pick-up in the direction of the disturbing source;
- P_3 is the probability that the victim receiver is stationary;
- P_4 is the probability of equipment generating a disturbing signal on a critical frequency;
- P_5 is the probability that the relevant harmonic is below the limit value;
- P_6 is the probability that the type of disturbing signal being generated will produce a significant effect in the receiving system;
- P_7 is the probability of coincident operation of the disturbing source and the receiving system;
- P_8 is the probability of the disturbing source being within the distance at which interference is likely to occur;
- P_9 is the probability of coincidence that the value of radiation at the edge of service area for the protected service just meets the limit for the RF disturbance;
- P_{10} is the probability that buildings provide attenuation.

Table 3 – Tabulation of the method of determining limits for equipment in the frequency range 0,150 MHz to 960 MHz

Frequency band [MHz]	**Radio service to be protected (non-exhaustive list)**	**Signal to be protected** dB(μ V/m)	**Protection ratio** dB	**Permissible interference field at receiving antenna** dB(μ V/m)	**Distance from equipment at which signal is to be protected** m	**Attenuation law**	**Approximate equi-valent interference field at 20 m from equipment** dB(μ v/m)	**Building attenuation** dB	**Allowance for probability** dB	**Corresponding practical limit at 30 m from boundary** dB(μ V/m)	**Corresponding limit at 30 m from boundary** dB(μ V/m)	**Proposal for revision of CISPR limits at 30 m on a test site** dB(μ v/m)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0,150 to 0,285	LF BC Aero-beacons											
0,285 to 0,490	Aero-beacons											
0,490 to 1,605	MF BC Aero-beacons											
1,605 to 4,00	Fixed links Aeromobile											
1,80 to 2,00	Amateur radio											
3,50 to 4,00	Amateur radio											
4,00 to 15,00	Fixed links Aeromobile											
7,00 to 7,30	Amateur radio											
10,10 to 10,15	Amateur radio											
14,00 to 14,35	Amateur radio											
15,00 to 20,00	Fixed links Aeromobile											
18,068 to 18,168	Amateur radio											

Table 3 *(continued)*

Frequency band	Radio service to be protected (non-exhaustive list)	Signal to be protected dB(μ V/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(μ V/m)	Distance from equipment at which signal is to be protected m	Attenuation law	Approximate equi-valent interference field at 20 m from equipment dB(μ v/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(μ V/m)	Corresponding limit at 30 m from boundary dB(μ V/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(μ v/m)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
20,00 to 30,00	Fixed links Aeromobile											
21,00 to 21,45	Amateur radio											
24,89 to 24,99	Amateur radio											
28,00 to 29,70	Amateur radio											
30,00 to 68,00	TV BC Land mobile											
50,00 to 54,00	Amateur radio											
68,00 to 72,00	Audio BC Land mobile											
76,00 to 87,50	TV BC Land mobile											
87,50 to 108,00	Audio BC											
108,00 to 156,00	ILS Aero-mobiles Land mobile											
144,00 to 148,00	Amateur radio											
156,00 to 174,00	Land mobile											

Table 3 *(end)*

Frequency band	Radio service to be protected (non-exhaustive list)	Signal to be protected dB(µ V/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(µ V/m)	Distance from equipment at which signal is to be protected m	Attenuation law	Approximate equivalent interference field at 20 m from equipment dB(µ v/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(µ V/m)	Corresponding limit at 30 m from boundary dB(µ V/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(µ v/m)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
216,00 to 400,00	ILS											
223,00 to 230,00	Amateur radio											
400,00 to 470,00	Fixed links Land mobile											
430,00 to 440,00	Amateur radio											
470,00 to 585,00	TV BC											
585,00 to 614,00	Aeronav TV BC											
614,00 to 854,00	TV BC											
854,00 to 960,00	Land mobile											
902,00 to 928,00	Amateur radio											

NOTE Explanation of column headings:

(3) Median value of the field strength to be protected at the edge of service area: to be derived from ITU regulations and ITU recommendations as appropriate.

(4) Protection ratio. The signal-to-interference ratio required to protect the radio service from interference with the characteristics of the signal generated by the disturbance source (for example, frequency stability, etc.). This is the value to be used in the derivation of limits and is not necessarily the same protection ratio as recommended by ITU for planning purposes.

(6) The mean minimum distance from the disturbance source at which receiving installations of the relevant radio service are normally installed. Disturbance sources at a different distance will be allowed for in the probability factor.

(9) The attenuation provided by buildings in which the disturbance source is installed. Experience has shown that 10 dB is a normal practical value.

5.6.3 Application of limits

The CISPR has traditionally adopted the view that there should be only one limit for each type of appliance. In the past, this approach has had considerable merit, but was increasingly difficult to sustain. Thus, it has been found useful to introduce several classes of limits, e.g. for disturbances from RF ISM equipment (see CISPR 11).

5.6.4 Overview of proposals for determination of disturbance limits for a given type of equipment

5.6.4.1 Determination of limits from practical experience

The exponents of this approach state simply that limits in use in their own country have been proved by practical experience to give adequate protection.

This is a powerful argument which cannot be ignored. The technical evaluation of coupling between sources of interference and communication services is very complex and virtually impossible to define precisely in mathematical or practical terms mainly because control of the various parameters is impossible and the spreads on measured values are very wide. Experience is therefore valuable. Unfortunately, the same factors which make experience valuable tend to militate against the acceptance of this approach unless the experience gained in a sufficiently large number of countries leads to similar conclusions. In this case, however, there is not a sufficiently large number of countries supporting the unqualified application of the actual limits but there is clearly a need to support the approach as one factor in the consideration of limits.

5.6.4.2 User and manufacturer responsibility for avoidance of interference

In a number of countries, user regulations are in force.

User limits may take one of several form outlines as follows:

a) regulations may require users of an appliance to meet certain limits if interference is caused;
b) if interference is caused, regulation may require an user of an appliance to cease operation until the interference is abated;
c) regulations based on the licensing of operation of a certain type of apparatus.

These approaches on their own satisfy neither the ITU/CISPR criteria for avoidance of interference nor the CISPR requirements for avoidance of technical barriers to trade. User limits would probably, in any case, be quite unacceptable in a number of countries as they place the user in an unfavourable position legally, financially and technically.

User regulations in conjunction with manufacturer regulations are a different matter. In these the user may be required to maintain suppression to the standard of new equipment and his financial, legal and technical obligations are therefore clear.

Examples of limits which are in use for user-only regulations are those in force in the United Kingdom for industrial radio-frequency heaters in the frequency range 0,15 MHz to 1 000 MHz. These broadly conform with the present CISPR limits with a provision of a 10 dB more stringent limit where interference is caused to safety of life services.

Other examples are the USA regulations which take the form described in item b) and the German regulations which take the form of item c). In the USA, the limits for RF ISM appliances are considerably less stringent than those recommended by CISPR.

5.6.4.3 Calculation of limits on a worst-case basis

This method of arriving at limits is intended to provide a high degree of protection for all radio communication services. Limits are calculated using minimum values of field strength to be protected, high values of protection ratio, maximum coupling between disturbance sources and radio communication receivers, and minimum values of attenuation with distance of the disturbing signal.

At first sight, this approach might seem to be ideal as it would, if implemented, lead to an ideal situation of very low values of man-made ambient radio-frequency noise. The cost to society of the adoption of such limits, however, would be high and it would be impossible, with present technology, to continue to operate many electrical devices, which would not contribute to the welfare and health of the human race.

5.6.4.4 Determination of limits by means of statistical evaluation

This approach states that the control of radio interference has to be treated statistically because the many factors involved are not under the control of the engineer and those parameters which are capable of measurement have very wide spreads of values.

The statistical evaluation approach has to overcome these difficulties. It should satisfy the communicator that communication services will receive adequate protection under normal circumstances of correct use, and the manufacturers and users of electrical equipment that economic, operational and safety considerations are being correctly taken into account.

5.6.5 Rationale for determination of CISPR limits in the frequency range below 30 MHz

5.6.5.1 General

With this subclause, a method for the estimation of disturbance limits for a given type of equipment is described. This approach can be applied for the frequency range below 30 MHz. For radiation coupling, dependence of the permissible disturbance field strength from the wanted signal μ_w, the signal-to-disturbance ratio R_p, and other influence factors can be estimated based on Equations (21) and (22) found in 5.5.

This model should be used by Product Committees to determine the disturbance limits measured on a EUT in standardized test sites. This model is considered suitable for point source magnetic field devices and not for distributed or complex systems.

Ten probability or influence factors P_1 to P_{10} have to be considered according to 5.6.2.3. However, for better alignment with terminology used for statistics the ten influence factors P_1 to P_{10} are further treated in their mean values as μ_{P1} to μ_{P10}. It shall be noted that the values for μ_{P1} to μ_{P10} can be used in logarithmic terms (i.e. in dB) only.

Taking into account Equation (22) we can write

$$E_{\text{Limit}} = \mu_i + t_\beta \sigma_i \quad (36)$$

Then taking equation (21) into account, noting that t_β = 0,84, and the limit becomes:

$$E_{\text{Limit}} = \mu_w - R_p + \mu_{P1} + \mu_{P2} + \mu_{P3} + \mu_{P4} + \mu_{P5} + \mu_{P6} + \mu_{P7} + \mu_{P8} + \mu_{P9} + \mu_{P10}$$

$$+ t_\beta \sigma_i - t_\alpha (\sigma_{P1}^2 + \sigma_{P2}^2 + \sigma_{P3}^2 + \sigma_{P4}^2 + \sigma_{P5}^2 + \sigma_{P6}^2 + \sigma_{P7}^2 + \sigma_{P8}^2 + \sigma_{P9}^2 + \sigma_{P10}^2)^{1/2} \quad (37)$$

where

E_{Limit} is the mean value of the permissible disturbance field strength at a specified distance d from the disturbance source;

μ_w is the minimum value of the wanted field strength at the edge of the service area of the radio service concerned;

R_p is the minimum acceptable value of the signal-to-disturbance ratio (i.e. the protection ratio) at the receiver's antenna port or feeding point;

μ_{P1} is the mean value of the main lobes of the magnetic dipole radiation in the direction of the victim receiver;

σ_{P1} is the standard deviation of P_1;

μ_{P2} is the expected mean value when the directional receiving antenna has its maximum pick-up in direction of the disturbance source;

μ_{P3} is the expected mean value when the victim receiver is stationary;

μ_{P4} is the expected mean value when there is equipment generating a disturbing signal on a critical frequency;

μ_{P5} is the expected mean margin when the relevant harmonic is below the limit value;

μ_{P6} is the expected mean value when the type of disturbance signal generated will produce a significant effect in the receiving system;

μ_{P7} is the expected mean value when the operation of the disturbance source is coincident with the receiving system;

μ_{P8} is the expected mean value when the disturbance source is located in a distance to the receiving system within which interference is likely to occur;

μ_{P9} is the expected mean value when the value of radiation at the edge of service area for the protected service just meets the limit for the RF disturbance;

μ_{P10} is the expected mean value when buildings provide attenuation.

Equation (37) is valid for mean values of influence factors (given in dB) assuming a log-normal distribution of their figures. Notice that the latter may not be fulfilled for each factor in each individual case. By inserting appropriate practical figures, Equation (37) can be used to estimate a limit E_{Limit} for the permissible disturbance field strength.

NOTE Within these calculations, 20 log has been utilized for distance elements and 10 log for the others, assuming power and not voltage.

5.6.5.2 Consideration and estimated values of μ_{P1} to μ_{P10}

5.6.5.2.1 Radiation pattern of the disturbance source (μ_{P1})

5.6.5.2.1.1 Consideration of μ_{P1}

The horizontal plane radiation pattern on a small purely magnetic antenna is described in dB unit by

$$G(\varphi) = G_{max} + 20 \log (\sin(\varphi)) \quad (38)$$

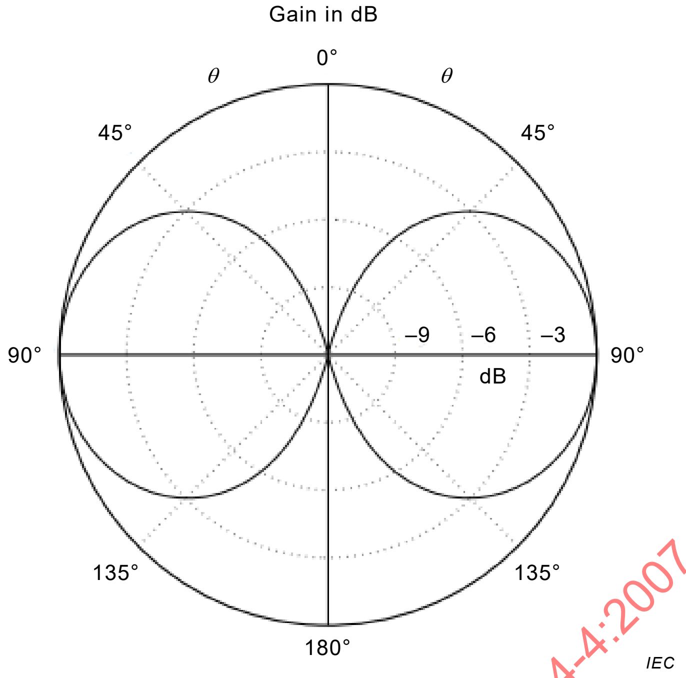


Figure 8 – horizontal plane radiation pattern on a small purely magnetic antenna

In the general case the victim may be in any possible direction with equal-probability. The mean value and standard deviation of the gain can be calculated by the following averages over half of the circle.

$$G_{avg} = Avg(G(\varphi)) \equiv \frac{1}{\pi} \times \int_0^{\pi} G(\varphi) d\varphi \quad (39)$$

$$\begin{aligned} \sigma_G{}^2 &= Avg\left(G(\varphi)^2\right) - \left(Avg(G(\varphi)\right)^2 \\ &= \frac{1}{\pi}\int_0^{\pi} (G(\varphi))^2 d\varphi - G_{avg}{}^2 \end{aligned} \quad (40)$$

Numerical calculation of Equations (39) and (40) gives the average gain $G_{avg} = G_{max} - 6{,}0$ dB and the standard deviation $\sigma_G = 7{,}9$ dB, which lead to $\mu_{P1} = G_{max} - G_{avg} = 6$ dB and $\sigma_G = 7{,}9$ dB

5.6.5.2.1.2 Estimation for the μ_{P1}

$\mu_{P1} = 6$ dB, $\sigma_{P1} = 8$ dB

5.6.5.2.2 Antenna gain of the victim to the disturbance source (μ_{P2}) (the directional receiving antenna have its maximum pick-up in direction of the disturbance source)

5.6.5.2.2.1 Consideration of μ_{P2}

In the frequency range below 30 MHz, a typical receiving antenna used with broadcast receivers is a rod antenna. Other antennas are also used. These antenna gains can vary to as much as –10 dB to 10 dB, however it can be assumed that 67 % of all antennas show a gain of within 3 dB of an isotropic antenna.

5.6.5.2.2.2 Estimation for the possible range of μ_{P2}

$$\mu_{P2} = -3 \text{ dB}, \sigma_{P2} = 3 \text{ dB}$$

5.6.5.2.3 Stationary receiver (μ_{P3})

5.6.5.2.3.1 Consideration of μ_{P3}

Below 30 MHz, it is likely that the victim receiver will be stationary; hence the value should be 0 dB.

5.6.5.2.3.2 Estimation for the possible range of μ_{P3}

$$\mu_{P3} = 0 \text{ dB}, \sigma_{P3} = 0 \text{ dB}$$

5.6.5.2.4 Equipment generating a disturbing signal at a critical frequency and relevant harmonics (μ_{P4})

5.6.5.2.4.1 Consideration of μ_{P4}

For the source of the magnetic disturbance from monitors and plasma TVs, the issue will appear for the fundamental frequency and the harmonics. Assuming the fundamental emission from the disturbance source is at 250 kHz and its harmonics will occupy approximately in the ratio of 5:1. Based upon a variation of ±25 kHz, giving a value of 50 kHz (7 dB).

For the source of the magnetic disturbance from induction cooking equipment, the issue will appear from the fundamental frequency and the harmonics. Assuming the fundamental emission from the disturbance source is at 50 kHz and its harmonics will occupy approximately in the ratio of 2:1. Based upon a variation of ±12,5 kHz, giving a value of 25 kHz (3 dB).

NOTE 1 The values below were derived from 10 log (1/5) = –7 dB and 10 log (1/2) = –3 dB hence the mean values 5 dB and the range of 2 dB.

NOTE 2 Other sources of disturbance may be from electrical car charging stations, phone charging systems and these are estimated to give similar values.

We have assumed no frequency dependency relevant to the limits.

A typical response of a source of magnetic field disturbance is present in Figure 9.

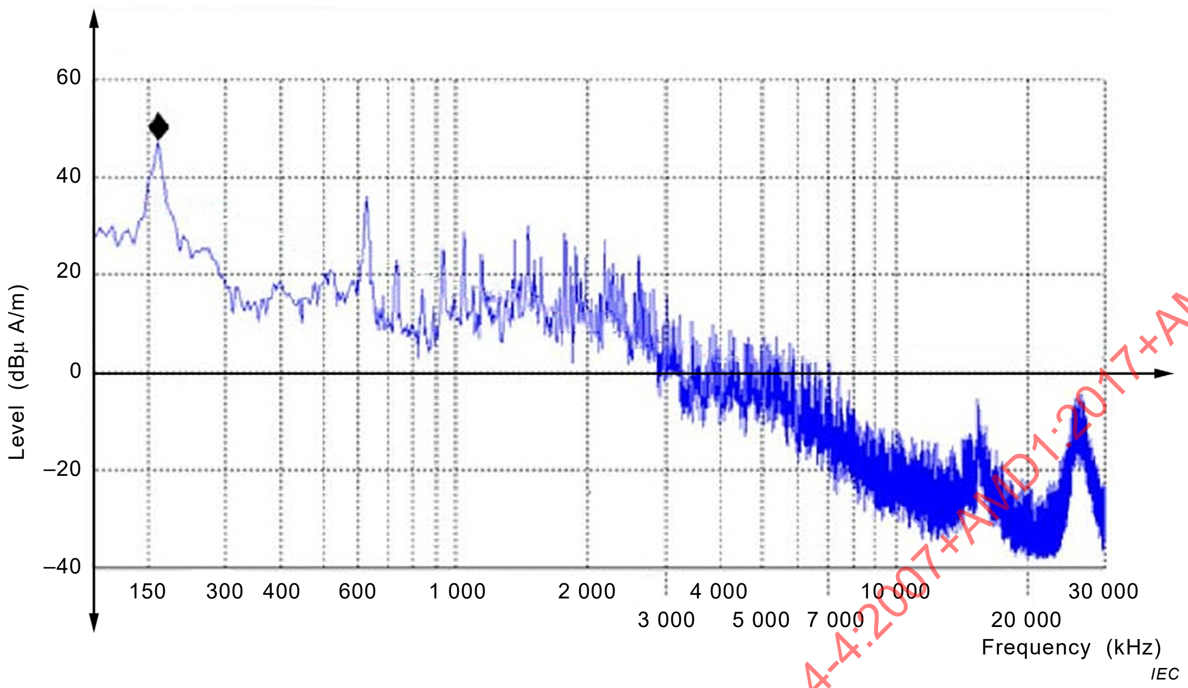


Figure 9 – typical source of magnetic field disturbance

5.6.5.2.4.2 Estimation for the possible range of μ_{P4}

$$\mu_{P4} = 5 \text{ dB, Range } \sigma_{P4} = 2 \text{ dB}$$

5.6.5.2.5 Margin that the relevant harmonics are below the limit value (μ_{P5})

5.6.5.2.5.1 Consideration of μ_{P5}

This value has been covered in μ_{P4}.

5.6.5.2.5.2 Estimation for the possible range of μ_{P5}

This value has been covered in μ_{P4}.

5.6.5.2.6 Expected mean value that the type of disturbance signal generated will produce a significant effect in the receiving system (μ_{P6})

5.6.5.2.6.1 Consideration of μ_{P6}

In the frequency range below 30 MHz, since the bandwidth of the unwanted signal and bandwidth of the receiver are of similar values, μ_{P6} should be set to 0 dB.

For the example of plasma TVs and induction cookers in the frequency range below 30 MHz, typically since the bandwidth of the disturbance source is greater than the bandwidth of the receiver, μ_{P6} should be set to 0 dB.

NOTE AC mains cable is not an issue of interference to radio receivers at the frequency below 30 MHz because this aspect is already covered by the conducted emission requirement defined in the standard.

5.6.5.2.6.2 Estimation for the possible range of μ_{P6}

$$\mu_{P6} = 0 \text{ dB, Range } \sigma_{P6} = 0 \text{ dB}$$

5.6.5.2.7 Expected mean value that the operation of the disturbance source is coincident with the receiving system operation of the disturbance source (μ_{P7})

5.6.5.2.7.1 Consideration of μ_{P7}

In the case that a receiver is operated for 24 hours, from the typical sources in 24 hours per day, plasma TV is 8 hours, PV Inverter 8 hours and induction cookers 2 hours operated.

NOTE The estimated values given in 5.6.6.2.7.2 were derived by 10 log (time of operation (hours) /24).

5.6.5.2.7.2 Estimation for the possible range of μ_{P7}

$$\mu_{P7} = 6{,}5 \text{ dB, Range } \sigma_{P7} = 3{,}5 \text{ dB}$$

5.6.5.2.8 The disturbance source is located in a distance to the receiving system within which interference is likely to occur (μ_{P8})

5.6.5.2.8.1 Consideration of μ_{P8}

The limit of the disturbance is specified for the test site with a normative fixed measurement distance *d*. In practice, the actual distance *r* between the disturbance source and the victim is usually quite different when the victim is used as intended.

The normative measurement distance *d* is 3 m. The ratio of the two distances *r* and *d* determines the additional attenuation.

The estimated value μ_{P8} usually increases the permissible limit and has to be added on the right hand side of Equation (37).

5.6.5.2.8.2 Estimation for the possible range of μ_{P8}

The value of μ_{P8} is calculated by:

$$\mu_{P8} = x \times 20 \log (r / d) \tag{41}$$

where

r is the actual distance between source and victim;

d is the measurement distance;

x is the wave propagation coefficient, typical value to be determined based upon Annex B.

The estimated distance has to take into account the average distance for the intended use of the radio equipment. Inserting practical distances into Equation (41) will provide the possible range of μ_{P8}.

5.6.5.2.9 The value of radiation at the edge of service area for the protected service (μ_{P9})

5.6.5.2.9.1 Consideration of μ_{P9}

Due to propagation complexities related to the transmission properties relating to this frequency range (including solar storms, variation of the reflecting condition at the ionosphere and the time of day) it is difficult to define actual coverage areas of the radio service. There will still be areas were the service will have sufficient signals and other areas where there will be insufficient. Hence a basic approximation could be based upon a simple circularly response and the ratio between the two different coverage areas.

5.6.5.2.9.2 Estimation for the possible range of μ_{P9}

$$\mu_{P9} = 3 \text{ dB, Range } \sigma_{P9} = 3 \text{ dB}$$

5.6.5.2.10 The expected mean value that buildings provide attenuation of the building (μ_{P10})

5.6.5.2.10.1 Consideration of μ_{P10}

In this frequency range the worst case attenuation of buildings will be 0 dB.

NOTE Depending on the situation, building attenuation can be taken into account. Any attenuation may impact both the reception of the radio service and the amount of interference source observed. Hence this may need to be taken into account with the performance of the receiving antenna.

5.6.5.2.10.2 Estimation for the possible range of μ_{P10}

$$\mu_{P10} = 0 \text{ dB, Range } \sigma_{P10} = 0 \text{ dB}$$

5.6.5.3 Rationale for determination of CISPR limits for photovoltaic (PV) power generating systems

For a model for the derivation of limits for photovoltaic (PV) power generating systems see Annex C.

5.6.5.4 Rationale for determination of CISPR limits for in-house extra low voltage (ELV) lighting installations

For a model for the estimation of radiation from in-house extra low voltage (ELV) lighting installations see Annex D.

5.6.6 Model for limits for the magnetic component of the disturbance field strength for the protection of radio reception in the range below 30 MHz

5.6.6.1 General

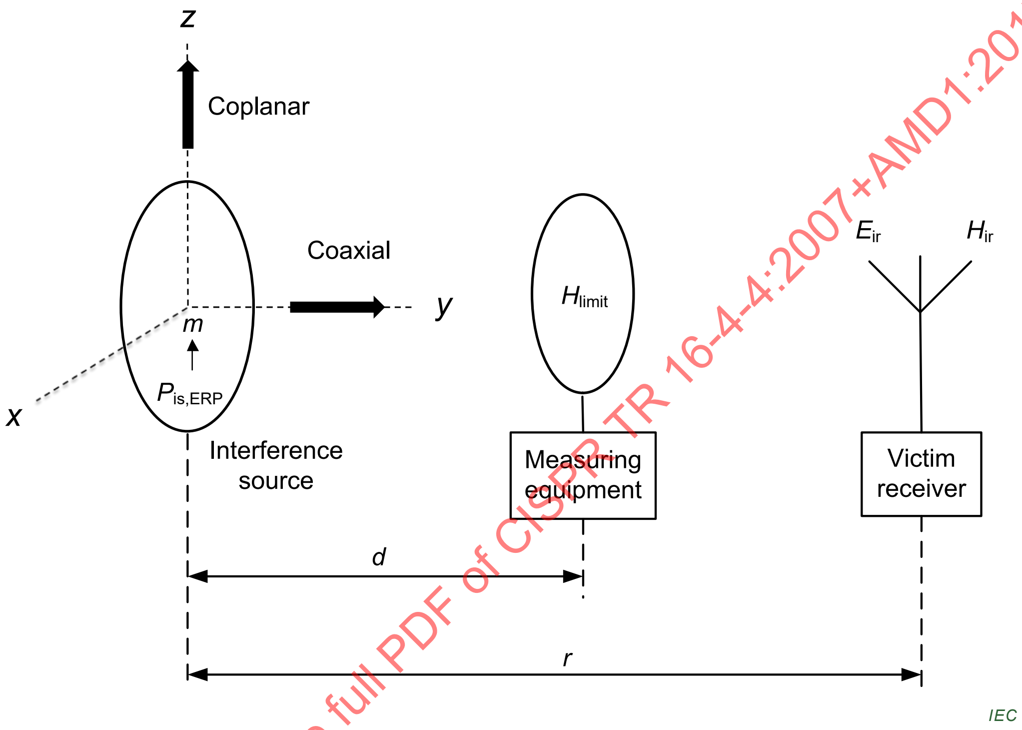
Recently, new electric or electronic devices having unintentional emissions below 30 MHz were introduced in the market. As the classical examples of these devices, there are plasma TV sets, power line communications devices, wireless power transfer, induction cooking devices, and so on. As the devices have been using increasingly, it is required to establish an appropriate model for deriving radiation limits in order to protect existing radio services at frequencies below 30 MHz.

This document contains statistics of complaints and mathematical models for the calculation of electric field limits related to the protection of radio services without the consideration of magnetic radiation within the near field region. Hence, development of other analytical models is required for the derivation of radiation limits on the devices having magnetic disturbances.

NOTE Other organisations also working within the area including CEPT and ITU-R.

5.6.6.2 Model for magnetic field limits below 30 MHz

This model is established for calculation magnetic field limits required for the protection of radio services against interference from various types of magnetic field sources using below 30 MHz. This method for calculation of magnetic field limits for protection of radio services below 30 MHz is depicted in Figure 10.



Key

m	magnetic dipole moment
E_{ir}	permissible interference electric field of victim receiver
H_{ir}	permissible interference magnetic field of victim receiver
$P_{is,ERP}$	effective radiated power of interference source at distance r from victim receiver
H_{limit}	magnetic field limits for interference source at measuring distance d, i.e. at the position of the antenna of the measuring equipment

Figure 10 – Model for magnetic field limit at measuring equipment

The permissible interference electric or magnetic field (E_{ir} or H_{ir}) of victim receiver can be derived from a method considering noise level or a method considering signal to disturbance ratio (R_P).

The method considering noise level is as follows:

E_{noise} (dBµV/m) of a victim service is corrected for the bandwidth of the victim receiver:

$$E_{noise} = E_{noise,b} + 10 \log (b_{victim} / b_{noise}) \quad (42)$$

where

b_{noise} is the measuring bandwidth of noise (kHz);

b_{victim} is the bandwidth of victim (kHz);

$E_{noise,b}$ is the electric field strength of noise from Recommendation ITU-R P.372 (dBμV/m).

NOTE $E_{noise,b}$ is defined by an ITU-R document as the background Gaussian noise level (excluding impulse and burst noises), assuming the reception with a loss-less omni-directional antenna and an ideal receiver. In the case that the antenna and feeder losses or receiver noise cannot be negligible, reference noise level should be defined by the system noise level.

In case of broadband interference, the bandwidth ratio *BWR* (dB) should be included to calculate the permissible interference electric field E_{ir} (dBμV/m):

$$E_{ir} = E_{noise} + \mathrm{BWR} \tag{43}$$

The bandwidth ratio is defined:

$$BWR = 10 \log (b_{measuring} - b_{victim}) \tag{44}$$

where

$b_{measuring}$ is measuring bandwidth of interferer (kHz).

When the bandwidth of the interfering signal is not wider than the victim receiver bandwidth, *BWR* = 0 dB should be assumed.

The method considering R_P is as follows.

In the case where the minimum received field strength E_{min} (dBμV/m) and the R_P (dB) of the victim receiver are known, the permissible interference electric field is calculated:

$$E_{ir} = E_{min} - R_P + BWR \tag{45}$$

From the permissible interference electric field, the permissible interference magnetic field H_{ir} (dBμA/m) can be obtained:

$$H_{ir} = E_{ir} - 51{,}5 \tag{46}$$

And then, the effective radiated power ERP of interference source at distance r from victim receiver can be determined by propagation attenuation loss between interference source and victim receiver. Propagation attenuation loss exponent is normally in the range of 2 to 4 (where 2 is for propagation in free space, 4 is for relatively lossy environments). In some environments, such as buildings, stadiums and other indoor environments, the propagation attenuation loss exponent can reach values in the range of 4 to 6.

The magnetic dipole moment *m* (Am^2) can be calculated from the effective radiated power of interference source at distance *r* from victim receiver, $P_{is,ERP}$ (kW) level.

$$m = \left(\frac{\lambda}{2\pi}\right)^2 \cdot \sqrt{50 \cdot P_{is,ERP}} \tag{47}$$

where

λ is the wavelength.

Finally, the magnetic field limits H_{limit} (A/m) for interference source at measuring distance d, i.e. at the position of the antenna of the measuring equipment can be calculated. The radiation direction from interference source is divided into coaxial and coplanar directions. The magnetic fields for these directions are computed by

$$H_{coaxial} = m \cdot \frac{\sqrt{\lambda_r^2 + d^2}}{2\pi\,\lambda_r d^3} \tag{48}$$

$$H_{coplanar} = m \cdot \frac{\sqrt{\lambda_r^4 - \lambda_r^2 d^2 + d^4}}{4\pi\,\lambda_r^2 d^3} \tag{49}$$

where

λ_r is the radian wavelength and is equal to $\lambda/2\pi$.

Then, H_{limit} is chosen to the maximum value of $H_{coaxial}$ and $H_{coplanar}$ in the view point of worst case as follows:

$$H_{limit} = \max(H_{coaxial}, H_{coplanar}) \tag{50}$$

5.7 Rational for determination of CISPR limits in the frequency range above 1 GHz

NOTE References found in this subclause are listed in ther Bibliography.

5.7.1 Introduction

In 5.6, another suitable method for estimation of emission limits for a given type of equipment is described. The same or similar approach can be used for the frequency range above 1 GHz. For radiation coupling, dependence of the permissible disturbance field strength from the wanted signal μ_w, the signal-to-disturbance ratio R_p, and other influence factors can be estimated based on Equations (21) and (22) found in 5.5.

Seven probability or influence factors P_1 to P_7 have to be considered. These influence factors take into account e.g. the antenna gain, the attenuation of the disturbance field strength as in Equation (21), and other conditions. However, for better alignment with terminology used for statistics the seven influence factors P_1 to P_7 are further treated in their mean values as μ_{P1} to μ_{P7}. It shall be noted that the values for μ_{P1} to μ_{P7} can be used in logarithmic terms (i.e. in dB) only.

Taking into account Equation (22) we can write

$$E_{Limit} = \mu_i + t_\beta \sigma_i$$

with t_β = 0,84, and the limit becomes:

$$E_{Limit} = \mu_w - R_p + \mu_{P1} + \mu_{P2} + \mu_{P3} + \mu_{P4} + \mu_{P5} + \mu_{P6} + \mu_{P7}$$
$$+ t_\beta \sigma_i - t_\alpha (\sigma_{P1}^2 + \sigma_{P2}^2 + \sigma_{P3}^2 + \sigma_{P4}^2 + \sigma_{P5}^2 + \sigma_{P6}^2 + \sigma_{P7}^2)^{1/2} \tag{36}$$

where:

E_{Limit} is the mean value of the permissible disturbance field strength at a specified distance *d* from the disturbance source;

μ_w is the minimum value of the wanted field strength at the edge of the service area of the radio service concerned;

R_p is the minimum acceptable value of the signal-to-disturbance ratio (i.e. the protection ratio) at the receiver's antenna port or feeding point;

μ_{P1} is the expected mean value that the major lobe of the disturbance field strength is not in the direction of the victim receiver;

μ_{P2} is the expected mean value that the directional receiving antenna does not have its maximum pick-up in direction of the disturbance source;

μ_{P3} is the expected mean value that for a mobile receiver the signal to noise ratio can be improved by keeping a certain distance to the disturbance source and that the mobile receiver is used well inside the respective radio service area;

μ_{P4} is the expected mean margin that the disturbance signal is below the limit;

μ_{P5} is the expected mean value that the type of disturbance signal generated will produce a significant effect in the receiving system;

μ_{P6} is the expected mean value that the disturbance source is located in a distance to the receiving system within which interference is likely to occur;

μ_{P7} is the expected mean value that buildings provide a certain degree of additional attenuation.

Due to lack of sufficient statistical data, Equation (36) is only analysed in terms of the mean values of the influence factors while neglecting the values for the standard deviation.

Equation (36) is valid for mean values of influence factors (given in dB) assuming a log-normal distribution of their figures. Notice that the latter may not be fulfilled for each factor in each individual case. By inserting appropriate practical figures, Equation (36) can be used to estimate a limit E_{Limit} for the permissible disturbance field strength.

For an estimation of limits related to the power of radiated disturbances, e.g. as needed for emission measurements in reverberation chambers, P_{Limit} can be derived from E_{Limit} (see Equation (36)) using the following equation:

$$E_{Limit}\,[\mathrm{dB}(\mu\mathrm{V/m})] = 104{,}8\ \mathrm{dB} + P_{limit}\,[\mathrm{dB(mW)}] + G_S\,[\mathrm{dB}] - 20\ \lg\,(d/d_{Ref)\ [dB)]} \quad (36a)$$

If *d* is the measuring distance (e.g. 3 m), and G_S is the gain of the disturbance source, which can be replaced by μ_{P1}, then

$$P_{limit}\,[\mathrm{dB(mW)}] = E_{Limit}\,[\mathrm{dB}(\mu\mathrm{V/m})] - 104{,}8\ \mathrm{dB} - \mu_{P1}\,[\mathrm{dB}] + 20\ \lg(d/d_{Ref)\ [dB)]}$$

and with d = 3 m (i.e. 20 lg$(d/d_{Ref)}$ = 9,5 dB) we get

$$P_{limit}\,[\mathrm{dB(mW)}] = E_{Limit}\,[\mathrm{dB}(\mu\mathrm{V/m})] - 95{,}3\ \mathrm{dB} - \mu_{P1}\,[\mathrm{dB}] \quad (36b)$$

5.7.2 Consideration and estimated values of μ_{P1} to μ_{P7}

5.7.2.1 Radiation pattern of the disturbance source (μ_{P1})

5.7.2.1.1 Consideration of μ_{P1}

Sources generating radiated disturbances in the frequency range above 1 GHz usually show directional radiation pattern which have one or more main lobes and also significant notches.

The influence factor describes the margin of an averaged pattern figure of the EUT to the disturbance level measured at maximum beam direction.

Factor μ_{P1} increases the permissible limit and has to be added on the right hand side of Equation (36b).

5.7.2.1.2 Estimation for the possible range of μ_{P1}

In [4] an antenna gain of about 6 dB is estimated for large EUTs, in the frequency range above 1 GHz. This could be interpreted such that on average, the disturbance field strength may be 6 dB below the maximum value measured on the test site.

In [5] it is estimated further that, for the frequency range above 1 GHz, measurement results obtained at the test site, on average will be about 6 dB below the maximum radiation of the disturbance sources. This means that the results obtained from test site measurements are, on average, significantly below the limit, owing to the radiation pattern. Reference [4] also gives evidence that for large increments of rotation the readings are on average 8,6 dB below the maximum, while with smaller increments the readings will be on average 3 dB below the maximum emission.

Radiation pattern of real EUTs are presented in [8]. These measurement results show that, in the frequency range 1 GHz to 3 GHz, the average radiation pattern is regularly about 3 dB to 6 dB below maximum radiation found at another nearby rotation position. It can also be seen that, at higher frequencies, the radiation pattern may branch more and more in each direction and that single beams with small beam widths appear.

Considering the facts in [4], [5], and [8] it is assumed that, on average, the disturbances are 3 to 8 dB below the maximum, meaning that:

μ_{P1} ranges from 3 dB to 8 dB.

5.7.2.2 Antenna gain of the victim to the disturbance source (μ_{P2})

5.7.2.2.1 Consideration of μ_{P2}

Radiated disturbances and wanted RF signals will usually reach the receiver's antenna from different directions. The gain G_w of the receiving antenna is available in direction of the wanted RF field strength. The disturbance field strength can be expected from a different direction, with the gain G_i. Therefore μ_{P2} represents the mean value of the difference of both gains. This difference gives the available gain G_{av} for the improvement of the actual signal to disturbance ratio R:

$$G_{av} = \mu_{P2} = G_w - G_i \tag{37}$$

The estimated value μ_{P2} increases the permissible limit and has to be added on the right hand side of Equation (36).

5.7.2.2.2 Estimation for the possible range of μ_{P2}

The antenna gain G_w of the radio receiver in direction of the wanted RF field strength depends on the radio service and can assume values between 0 dB (for mobile radio services, such as GSM, DCS, or UMTS) and 80 dB (for certain fixed radio services). In the frequency management, a value of G_i = 6 dB is used for the gain in other directions if the gain in the main lobe of the receiver antenna is greater than 6 dB.

In respect of EMC the following range should be used:

$$\mu_{P2} = G_w - 6\,\text{dB}\Big|_{6\,\text{dB} < G_w \leq 12\,\text{dB}} \quad \text{and } \mu_{P2} = 6\,\text{dB}\Big|_{G_w > 12\,\text{dB}}$$

5.7.2.3 Mobile receiver (μ_{P3})

5.7.2.3.1 Consideration of μ_{P3}

This factor takes into account that a mobile receiver can always be moved away from the disturbance source and that the receiver will be provided, inside the radio service area, with a wanted RF field strength which is stronger than the minimum wanted RF field strength at the edge of the service area.

The estimated value μ_{P3} increases the permissible limit and has to be added on the right hand side of Equation (36).

5.7.2.3.2 Estimation for the possible range of μ_{P3}

From a frequency management point of view, for mobile radio services and particularly for base stations there is a need for more RF channels if radiated disturbances increase within the wanted radio frequency (RF) band, in a given area and environment. This is the reason why the frequency management can only propose a factor of 0 dB, for μ_{P3}. From representatives of other branches of industry it is required that the worst case can not be used for the estimation of disturbance limits. From the latter perspective, it would be possible to tolerate values for factor μ_{P3} in the range of 6 dB.

Furthermore, the mobile receiver is used rather seldom at the edge of the service area, in particular if a cellular radio service is considered. Therefore the wanted RF field strength used for calculation of the permissible disturbance field strength should be, on average, higher than the minimum wanted RF field strength required at the edge of the service area.

Considering the physical laws, the wanted RF field strength decreases linearly with distance while the service area increases with the square of this distance. For consideration of the mobility of the receiver, the wanted RF field strength at the edge of half of the service area is used.

The service area depends on the distance by square root of the distance. The field strength depends on the distance linearly. This means:

$$0{,}5 \cdot A = \left(\frac{d}{\sqrt{2}}\right)^2 \cdot \frac{\pi}{4} \qquad (38)$$

and

$$E_\mathrm{w}(d) = 7 \cdot \frac{\sqrt{P_\mathrm{w} \cdot G_\mathrm{w}}}{\left(\frac{d}{\sqrt{2}}\right)} \qquad (39)$$

Under this condition the wanted RF field strength E_w used for calculation can be increased by 3 dB, compared to the minimum wanted RF field strength required at the edge of the service area. Instead of using an increased-by-3-dB wanted RF field strength for the calculation of the respective disturbance limit one can also continue to use the minimum wanted RF field strength required at the edge of the service area and add the 3 dB to the influence factor μ_P3.

The possibilities for mobile radio receivers to be used well inside a given service area and to extend the distance to the disturbance source by being moved away from that source should be taken into account by setting the range for the mean value μ_P3 of the influence factor from 0 dB up to 9 dB:

μ_P3 ranges from 0 dB to 9 dB.

5.7.2.4 Emission level of the disturbance source is below the limit (μ_P4)

5.7.2.4.1 Consideration of μ_P4

Usually, disturbances from a certain source do not just meet the limits, but have a certain margin to them. Factor μ_P4 counts for the estimated average of the minimum margin of the disturbance to the limit.

The estimated value μ_P4 increases the permissible limit and has to be added on the right hand side of Equation (36).

5.7.2.4.2 Estimation for the possible range of μ_P4

An EUT conforms with the limit when the maximum disturbance emission is below (or equal to) the limit. This also means that the difference between the limit and the disturbance is greater than (or equal to) zero.

Contribution [7] contains an estimation of the margin to the limit for 49 samples of class A and class B IT equipment. The average margin to the FCC limit for all 49 products is about 12 dB.

The 273 measurement values of the margin to the limit reported in [7] are distributed over a range from -2,6 dB to +31,9 dB.

As a result of this investigation it can be assumed that μ_P4 is usually in the range of:

μ_P4 ranges from 0 dB to 24 dB.

5.7.2.5 Interference depending on the bandwidth of the radio service (μ_P5)

5.7.2.5.1 Consideration of μ_P5

For continuous broadband disturbances, the interference potential to a receiving system depends on the wanted RF signal bandwidth of the victim receiver. The higher the wanted RF signal bandwidth B_want of the victim receiver or its respective radio service is, the higher the interference potential would be, compared to the RF bandwidth B_meas of the measurement receiver. That also means that the interference potential is lower if the RF bandwidth of the radio service is smaller than that of the measurement receiver. Eventually, the interference potential of a source of broadband disturbances also depends on the ratio of the bandwidth B_{noise} of the broadband disturbance to the bandwidth of the wanted radio signals B_{want} actually considered.

In practice, three cases may occur that require adequate consideration.

Case a) $B_{want} < B_{noise} < B_{meas}$

In this case, calculation of μ_{P5} shall deliver negative dB values, since not only one receiving channel may be interfered with, but several ones.

In view of this, the permissible broadband disturbance can be described by Equation (40a) as ratio of the bandwidth for the considered individual radio service to the bandwidth of the broadband disturbance:

$$E_p = E_m \sqrt{\frac{B_{want}}{B_{noise}}} \quad (40a)$$

where:

E_m is measured disturbance field strength;

E_p is permissible disturbance field strength for the considered radio service;

B_{noise} is bandwidth of the broadband disturbance;

B_{want} is bandwidth of the considered radio service for the wanted signal.

For estimation of the decrease required for the permissible disturbance field strength, the value of μ_{P5} can be calculated by Equation (41a):

$$\mu_{P5} = 10 \cdot \log_{10} \left[\frac{B_{want}}{B_{noise}} \right] \quad (41a)$$

Case b) $B_{meas} < B_{noise} < B_{want}$

In this case, calculation of μ_{P5} can deliver positive dB values, since the disturbance may not occupy the whole receiving channel of the victim receiver concerned.

In view of this, the permissible broadband disturbance can be described by Equation (40b) as ratio of the bandwidth of the broadband disturbance to the bandwidth of the measuring receiver:

$$E_p = E_m \sqrt{\frac{B_{noise}}{B_{meas}}} \quad (40b)$$

where:

E_m is measured disturbance field strength;

E_p is permissible disturbance field strength for the considered radio service;

B_{noise} is bandwidth of the broadband disturbance;

B_{meas} is bandwidth of the measurement receiver.

For estimation of a relaxation possible for the permissible disturbance field strength, the value of μ_{P5} can be calculated by Equation (41b):

$$\mu_{P5} = 10 \cdot \log_{10}\left[\frac{B_{noise}}{B_{meas}}\right] \quad (41b)$$

Case c) $B_{noise} > B_{meas}$ and B_{want}, respectively

In this case of true broadband disturbance, calculation of μ_{P5} can deliver positive as well as negative dB values, since the assessment result only depends on the ratio of the wanted RF signal bandwidth to the measurement bandwidth.

In view of this, the permissible broadband disturbance can be described by Equation (40c) as ratio of the bandwidth of the considered individual radio service to the measurement bandwidth:

$$E_p = E_m \sqrt{\frac{B_{want}}{B_{meas}}} \quad (40c)$$

where:

E_m is measured disturbance field strength;

E_p is permissible disturbance field strength for the considered radio service;

B_{meas} is bandwidth of the measuring receiver;

B_{want} is bandwidth of the considered radio service for the wanted signal.

For estimation of an increase or decrease allowed for the permissible disturbance field strength, the value μ_{P5} can be calculated by Equation (41c):

$$\mu_{P5} = 10 \cdot \log_{10}\left[\frac{B_{want}}{B_{meas}}\right] \quad (41c)$$

The estimated value of μ_{P5} for broadband services has to be added on the right hand side of Equation (36).

5.7.2.5.2 Estimation for the possible range of μ_{P5}

The value of μ_{P5} can be calculated by Equation (41) and is determined by the bandwidth of the considered radio service.

5.7.2.6 Ratio of the distance between source and victim to the measurement distance (μ_{P6})

5.7.2.6.1 Consideration of μ_{P6}

The limit of the disturbance emission is specified for the test site with a normative fixed measurement distance *d*. In practice, the actual distance *r* between the disturbance source and the victim is usually quite different when the victim is used as intended.

The normative measurement distance *d* is 3 m. The ratio of the two distances *r* and *d* determines the additional attenuation.

The estimated value μ_{P6} usually increases the permissible limit and has to be added on the right hand side of Equation (36).

5.7.2.6.2 Estimation for the possible range of μ_{P6}

The value of μ_{P6} is calculated by:

$$\mu_{P6} = x \cdot 20 \cdot \log_{10}\left[\frac{r}{d}\right] \tag{42}$$

where

r = actual distance between source and victim;

d = measurement distance;

x = wave propagation coefficient, which is 1 in free-space propagation and somewhat higher (1 to 1,5) for non-free-space propagation.

The estimated distance has to take into account the average distance for the intended use of the radio equipment. Inserting practical distances into Equation (42) will provide the possible range of μ_{P6}.

NOTE In special areas, where use of mobile radio communication equipment is not permitted, larger distances r can be used for calculation. The estimated limit is valid only for such environments.

5.7.2.7 Attenuation of the building (μ_{P7})

5.7.2.7.1 Consideration of μ_{P7}

An additional attenuation between the disturbance source and the victim reduces the level of disturbance and depends on the position of source and victim. Two options for calculating the permissible disturbance field strength are considered: option a), where the disturbance source and the victim are inside the building and option b), where one is inside the building and the other is outside.

The estimated value μ_{P7} increases the permissible limit and has to be added on the right hand side of Equation (36).

5.7.2.7.2 Estimation for the possible range of μ_{P7}

For option a) it is assumed that an attenuation value in the range of 0 dB to 6 dB is suitable. For option b), an attenuation value in the range of 2 dB to 20 dB is assumed.

Depending on the location of the victim and disturbance source it is proposed that the following be used:

μ_{P7} ranges from 0 dB to 20 dB.

5.7.3 Equivalent EMC environment below and above 1 GHz

In 5.6.4 it is also mentioned that calculation of limits based on statistics can not be the one and only way of estimating CISPR limits. Positive practical experience with existing limits is also a powerful argument. For this reason, the ratio of limits at about 1 GHz as borderline between existing limits and new limits can be considered. However, as radio services above 1 GHz are mainly based on different technologies they can be regarded more robust compared to the analogue techniques which were the basis for limits below 1 GHz. For the calculation it is assumed that radio services and applications operating at frequencies above or below 1 GHz are to be protected in the same way.

For such a comparison the same mobile radio service in the frequency range above 1 GHz as in the frequency range below 1 GHz may be used. For this comparison consideration of the limits of GSM (900 MHz) and DCS (1800 MHz) may be useful, owing to the fact that both radio services have comparable functional parameters.

Table 4 contains the relevant data of protected wanted RF field strength, the CISPR limit for measurements with a quasi-peak (QP) detector at a measurement distance of 10 m under free field conditions, and the procedure for the estimation of an equivalent limit at 1 800 MHz for the different measurement procedure under free-space wave propagation conditions, with a different detector type and a different measurement bandwidth.

Factor *x* (dB) takes into account a transposition of the appropriate limit from CISPR 22 at about 900 MHz from 10 m to 3 m measurement distance normally used for disturbance measurements in the frequency range above 1 GHz. This shall be added to the CISPR limit.

Factor *y* (dB) takes into account the transfer from free-field wave propagation conditions (as e.g. at OATS) to free-space wave propagation conditions as normally defined for disturbance measurements in the frequency range above 1 GHz. This shall be subtracted from the CISPR limit.

Eventually, the difference *d* between the estimated limit and the wanted RF field strength at 900 MHz can be used for estimation of the CISPR limit at 1 750 MHz.

Table 4 – Calculation of permissible limits for disturbances at about 1 800 MHz from existing CISPR limits in the frequency range of 900 MHz

	GSM at about 900 MHz	**DCS at about 1 800 MHz**
Protected wanted RF field strength	32 dB(μV/m)	42 dB(μV/m)
Transfer limit of 37 dB(μV/m) at 10 m to 3 m by addition of x dB	(37+x) dB(μV/m)	-
Transfer OATS to free space conditions by subtraction of y dB	(37+x-y) dB(μV/m)	-
Transfer QP to AV detector [a]	(37+x-y) dB(μV/m) + about z dB	-
Transfer 120 kHz to 1 MHz measurement bandwidth by addition of 9,2 dB	(37+x-y + z) dB(μV/m) + about 9,2 dB	-
Difference *d* between the CISPR limit for permissible disturbance and the wanted RF field strength at 900 MHz	*d* = [(37+x-y + z) dB + 9,2 dB] - 32 dB	-
Resulting limit for permissible disturbances at 1800 MHz	-	(42 + *d*) dB (μV/m)

[a] In case of CW-type disturbances the use of an average detector does not require additional corrections. However a factor z is provided for appropriate consideration of non-continuous disturbances.

5.7.4 Overview on parameters of radio communication services operating in the frequency range above 1 GHz and up to 16 GHz with effect to electromagnetic compatibility

Table 5 contains a list of radio communication services operating in the frequency range above 1 GHz and up to 16 GHz. It contains valuable data of radio parameters with relevance to EMC. The data set out in Table 5 can be used to calculate limits for permissible disturbances emanating from equipment, systems or even installations, in the frequency range above 1 GHz. For such calculations and estimations, the model set out in 5.7 should be used.

The readers and users of the present document are invited and encouraged to accomplish the entries in Table 5 by their own data and to submit their findings to Subcommittee H of CISPR, which is responsible for maintenance of this CISPR Report.

Table 5 – List of radio services, typical parameters, and influence factors

Radio system (name)	Receiving frequency band / MHz	Protected wanted field strength Ew/dB(µV/m)	Protection ratio R / dB	Tolerable interferer /dB(µV/m)	Bandwidth of radio service /kHz	Gain of victim antenna / dB	Operation time of receiver/ day (%)	Isolation distance / m	**P1**: gain of disturb. Source	**P2**: Gain of victim antenna	**P3**, h: Victim is mobile	**P4**: emission below limit	**P5**: Type of emission Broadband correc.	**P6**, l: distance to victim	**P7**, f-manag.: building attenuation	**P7**, manufact.: building attenuation	Permissible disturb. manufacture Ed/dB(µV/m)	Permissible disturb. F-management Ed/dB(µV/m)
Navigation aid	1 085 - 1 095	56	8	48	10 000	11												
Radioamateur	1 240 - 1 300	-5	10	-15	3	6												
Radar	1 250 - 1 260	31	20	11	500	35												
T-DAB	1 452 - 1 462	43	28	15	1 540	0												
	1 452 - 1 463	43	28	15	1 540	0												
GPS	1 575.42	5	-36	41	1 000	0												
GSM 1800 base	1 710 - 1 785	38	9	29	200	18												
GSM 1800 mobile	1 805 - 1 880	40,5	9	31,5	200	0												
	1 805 - 1 881	42	9	33	200	0												
GSM	1 710 - 1 805	38	9	29	200	0												
	1 710 - 1 806	38	9	29	200	0												
DECT	1 880 - 1 900	59	10	49	1 700	0												
UMTS FDD base	1 920 - 1 980	23	-6	29	5 000	18												
UMTS FDD mobil	2 110 - 2 270	26	-9	35	5 000	0												
UMTS TDD	1 900 - 2 025	25	-10	35	5 000	35												
UMTS extension	2 500 - 2 690	26	-9	35	5 000	0												
Radioamateur	2 320 - 2 400	4,5	6	-1,5	3	6												
BOS/ Broadcast	2 320 - 2 500	69	30	39	14 000	6												
Fixed serv. PMP	2 540 - 2 670	43	26	17	14 000	6												
Radar	2 700 - 2 900	37	10	27	1 000	33												
Radioamateur	3 400 - 3 475	8	10	-2	3	12												
Fixed serv. PMP	3 410 - 3 580	46	36	10	14 000	18												
Fixed serv. PMP	3 800 - 4 200	49	36	13	29 000	45												
HPERLAN/1	5 200	68	12	56,3	23 500	0												
WLAN	5 150 - 5 725	69	16	53	20 000	0												
Radioamateur	5 650 - 5 850	12	10	2	3	12												
Demo.radio	5 725 - 5 875	38	10	28	200	0												

Table 5 *(continued)*

Radio system (name)	Receiving frequency band / MHz	Protected wanted field strength Ew/dB(µV/m)	Protection ratio R / dB	Tolerable interferer /dB(µV/m)	Bandwidth of radio service /kHz	Gain of victim antenna / dB	Operation time of receiver/ day (%)	Isolation distance / m	**P1**: gain of disturb. Source	**P2**: Gain of victim antenna	**P3**, h: Victim is mobile	**P4**: emission below limit	**P5**: Type of emission Broadband correc.	**P6**, l: distance to victim	**P7**, f-manag.: building attenuation	**P7**, manufact.: building attenuation	Permissible disturb. manufacture Ed/dB(µV/m)	Permissible disturb. F-management Ed/dB(µV/m)
Remote control	5 725 - 5 875	42	10	32	2500	0												
Fixed serv. PMP	5 930 - 6 419	54	36	18	30 000	60												
Fixed service	6 425 - 7 125	56	36	20	40 000	50												
Fixed service	7 137 - 7 413	69	36	33	14 000	44												
Narrowb, fixed services	7 413 - 7 425	30	36	-6	100	44												
Fixed service	7 425 - 7 725	55	36	19	28 000	44												
Demo.radio	9 235 - 9 475	42	10	32	200	0												
Radar	9 185 - 9 170	42	10	32	2 500	34												
Radio amateur	10 000 - 10500	17	6	11	3	12												
Sat. Broad./1MHz	11 400 - 12 400	60	23	37	1 000	0												
Fixed service	12 750 - 13 250	60	36	24	28 000	49												
Fixed service	15 320 - 15 350	59	36	23	14 000	47												

Annex A

Excerpt from CISPR Report No. 31 Values of mains decoupling factor in the range 0,1 MHz to 200 MHz

(This Report provides a partial answer to Study Question No. 54/1 of 1964 which remains under consideration.)

(Stresa, 1967)

1. Figure 1, page 50, shows median values, standard deviations and minimum values of mains decoupling factor, defined as the ratio of voltage injected into the mains and the resultant voltage measured at the end of a terminated aerial feeder. The values indicated were obtained by various authors (see references below) under different conditions of measurement. They generally apply to an asymmetrical source connected in a random manner between the "phase" and "null" conductor of a single phase mains supply system * and to well screened receivers. In the frequency range up to 30 MHz, the data apply mainly to receiving installations with indoor aerials (excluding ferrite aerials); above this frequency, most of the coupling measurements were made at installations with outdoor aerials.
2. In Figure 2, page 51, an attempt is made to synthesize the available data, taking as far as possible account of the differences between the various sources. It is believed that the curves shown represent a conservative estimate of the decoupling factor to be expected between sources and receivers located in the same or immediately adjoining apartments of the same building.
3. Figure 3, page 51, shows typical distributions of measured values which may be used to determine decoupling factors for a percentage of cases other than 50%.

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ii) V. P. Pevnicki, F. E. Ilgekit: *Charakteristiki systemi podavlenia radiopomech*. Elektricestvo 1956, Nr. 6.

iii) V. V. Roditi, M. S. Garcenstein: *Priomnye antenny i industrialnye radiopomechi*. Radiotechnika 1956, Nr. 9.

iv) *Reports of the Research Institute of Telecommunications (VUS)* - Prague Nr. 339/1961 and Nr. 1968/66.

v) Interim Report VUS 1965/1966.

vi) Document C.I.S.P.R.(U.K.)376.

vii) Documents C.I.S.P.R./WG6(U.K./McLachlan) 6,7.

Secretarial Note. The C.I.S.P.R. Secretariat does not hold copies of the above documents. If these are required, application should be made to the National Corresponding Member of the Working Group concerned.

* In the United Kingdom measurements, the asymmetrical source was connected between the earth conductor and the line and neutral conductors connected together in the manner indicated in Figure 4A, page 52.

APPENDIX A TO REPORT 31

In the measurement of mains decoupling factor, the following principal requirements must be observed:

1. The internal resistance, the symmetry to ground and the polarity of connection to the mains of the signal source used for measurement should correspond to similar parameters of actual appliances.
2. The output voltage of the source should be measured by the methods used for checking compliance with limits.
3. Throughout the whole measurement, actual receiving aerials as found at the measured locations should be used.
4. The input impedance of the measuring receiver should approximate, as closely as possible, to the value of the input impedance of normal receivers.
5. The sites investigated should correspond qualitatively and quantitatively to the location at which the results will be used.

The statistical evaluation is usually carried out as if the data belonged to a single statistical set of random values. Using this method, the range of distances up to which measurements are carried out becomes very important because the average value and spread measured at a given site depends not only on the properties of the electrical installations and on the building attenuation, but also to a great extent on the area around the source covered by measurements. For example, by increasing this area, it is possible to obtain a lower average and higher spread of the decoupling factor. It is therefore necessary to limit the extent of data used for statistical evaluation to decoupling factors for which interference might still be expected with a given terminal voltage limit, a given protection ratio, and a given minimum usable sensitivity of receivers.

The decoupling factor a_{max} beyond which interference is no longer likely to occur and which ought consequently to be excluded from the evaluation, may be calculated from the following equation:

$$L - a_{max} = s - p$$

where

a_{max} = maximum decoupling factor (in decibels)

L = terminal voltage limit (in decibels over 1 μV)

s = minimum usable sensitivity of receivers considered (in decibels over 1 μV)

p = protection ratio (in decibels).

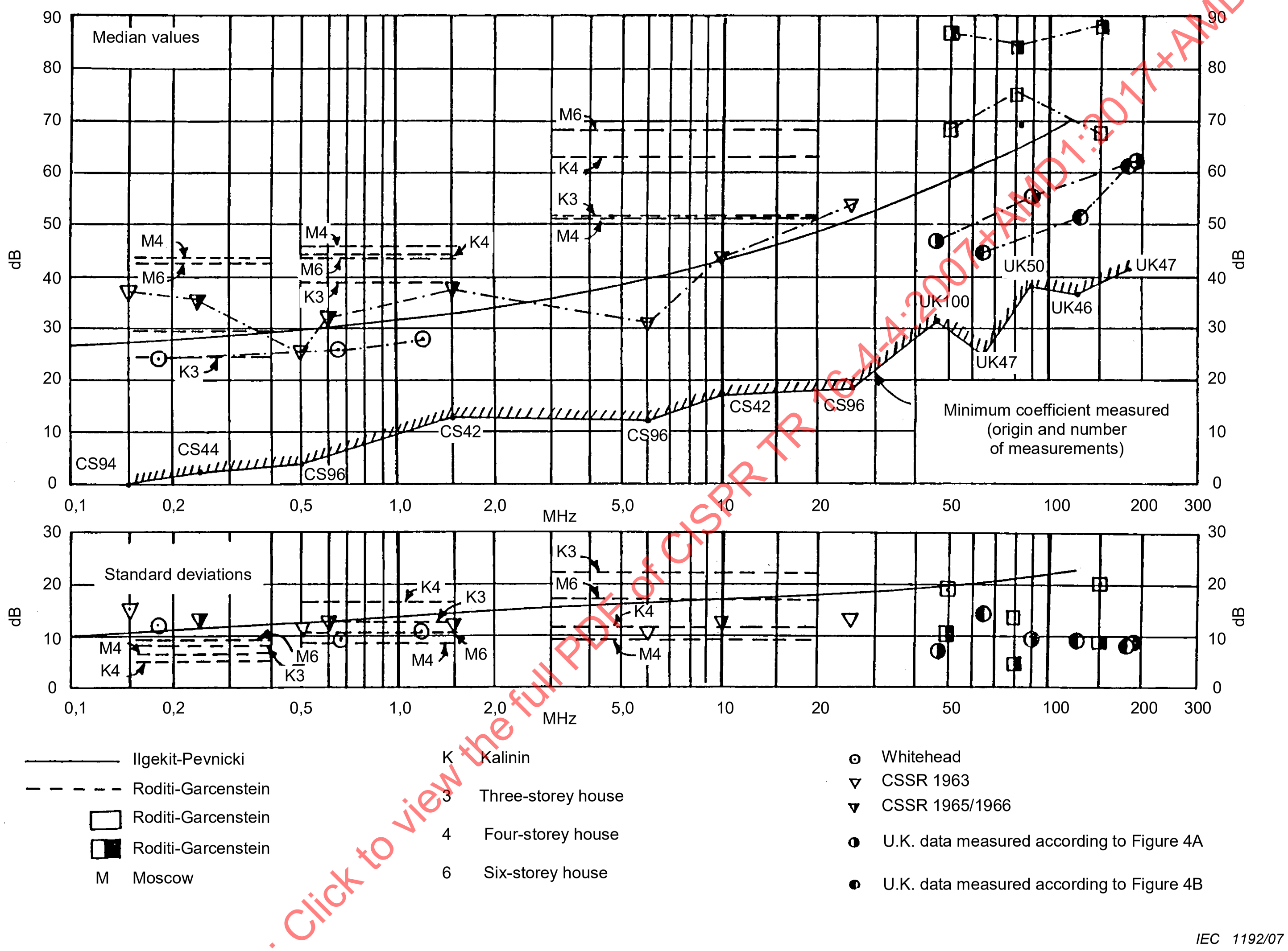


Figure A.1 – Mains decoupling coefficient as measured by various authors

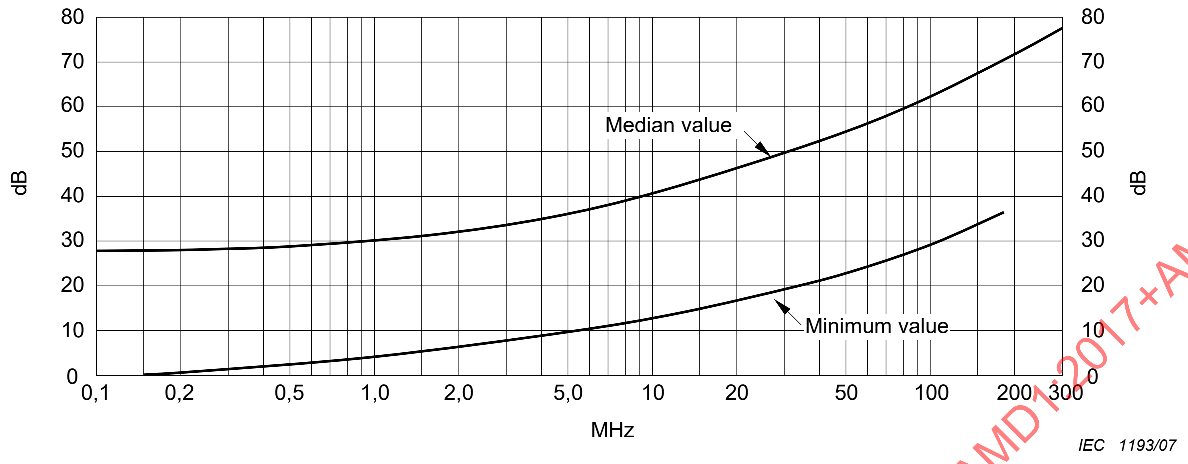


Figure A.2 – Median and minimum values of mains decoupling factor for the range 0,1 MHz to 200 MHz

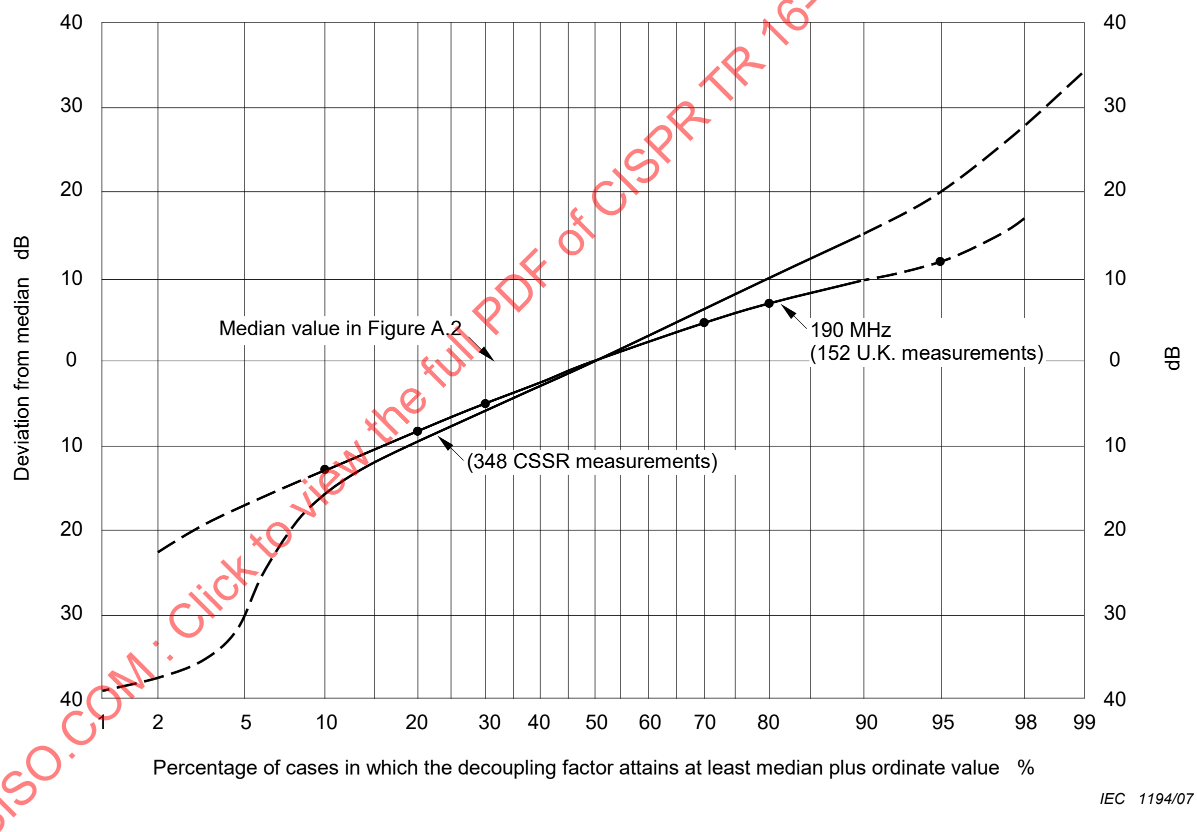


Figure A.3 – Typical distributions of deviations from median value of decoupling factor as indicated in Figure A.2

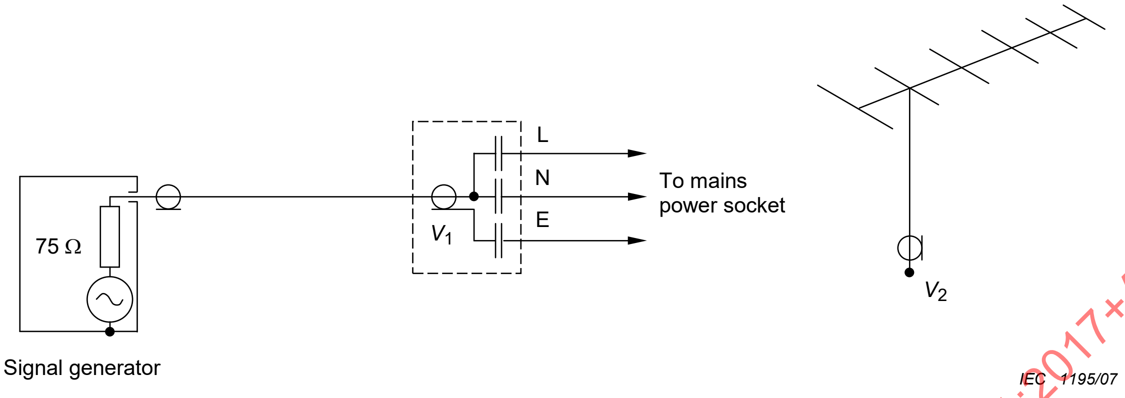


Figure A – Measurement with signal generator

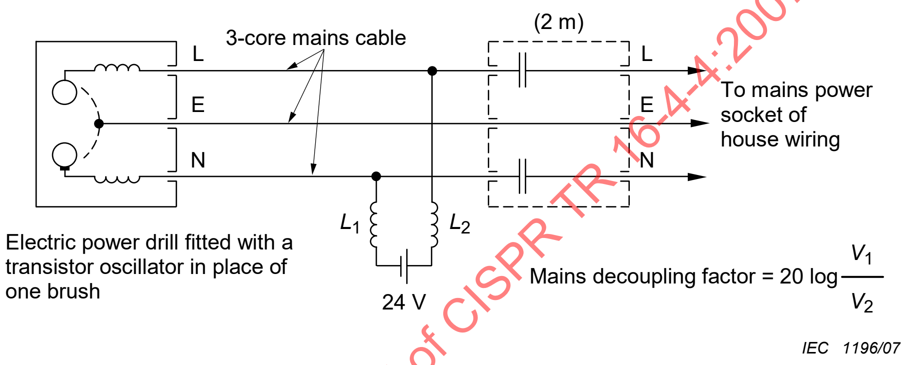


Figure B – Measurement using actual appliance

Figure A.4 – Measurement of the mains decoupling factor

Annex B
(informative)

Conversion of H-field limits below 30 MHz for measurement distances

B.1 Background

In order to determine the H-field conversion factor within the boundary of the test environment containing the ground plane, a commercial 3D full wave simulation tool has been used and the calculation thereof along with measurement records are provided in the following paragraphs.

Figure B.1 illustrates a designed model using a commercial tool. The dimension of the ground plane is 30 m x 40 m. The radius of the loop antenna, which is 0,6 m and the centre of the antenna is 1,3 m above the surface of the ground plane. For the measurement of field, the probes are located at 3 m and 10 m, both at coaxial and coplanar direction (a: coaxial at 3 m, b: coaxial at 10 m, c: coplanar at 3 m, d: coplanar at 10 m).

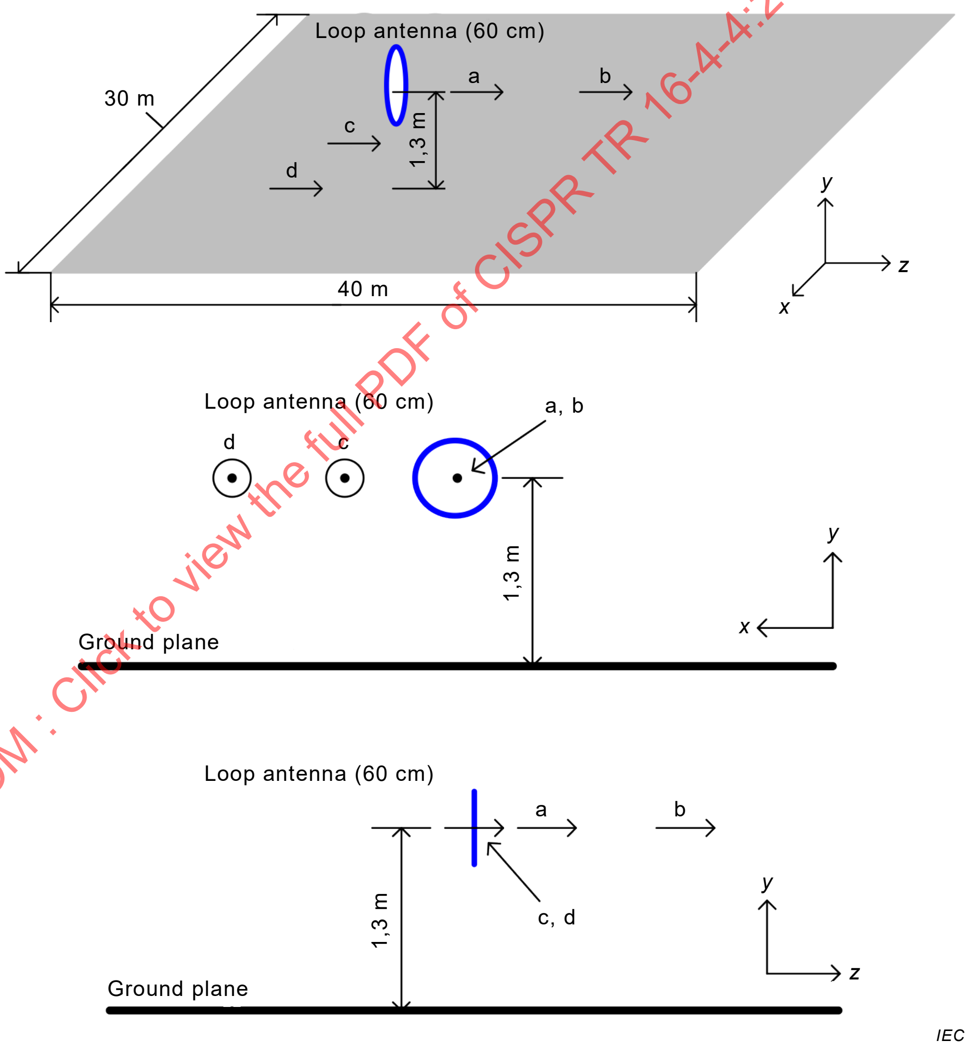


Figure B.1 – Commercial tool model for H-field conversion

Figure B.2 depicts another designed model using a commercial tool, and the ground plane has been removed in order to apply image theory with an additional virtual loop antenna positioned at 1,3 m below the ground plane that has been removed. This model is intended to measure coaxial and coplanar direction component from the same probe.

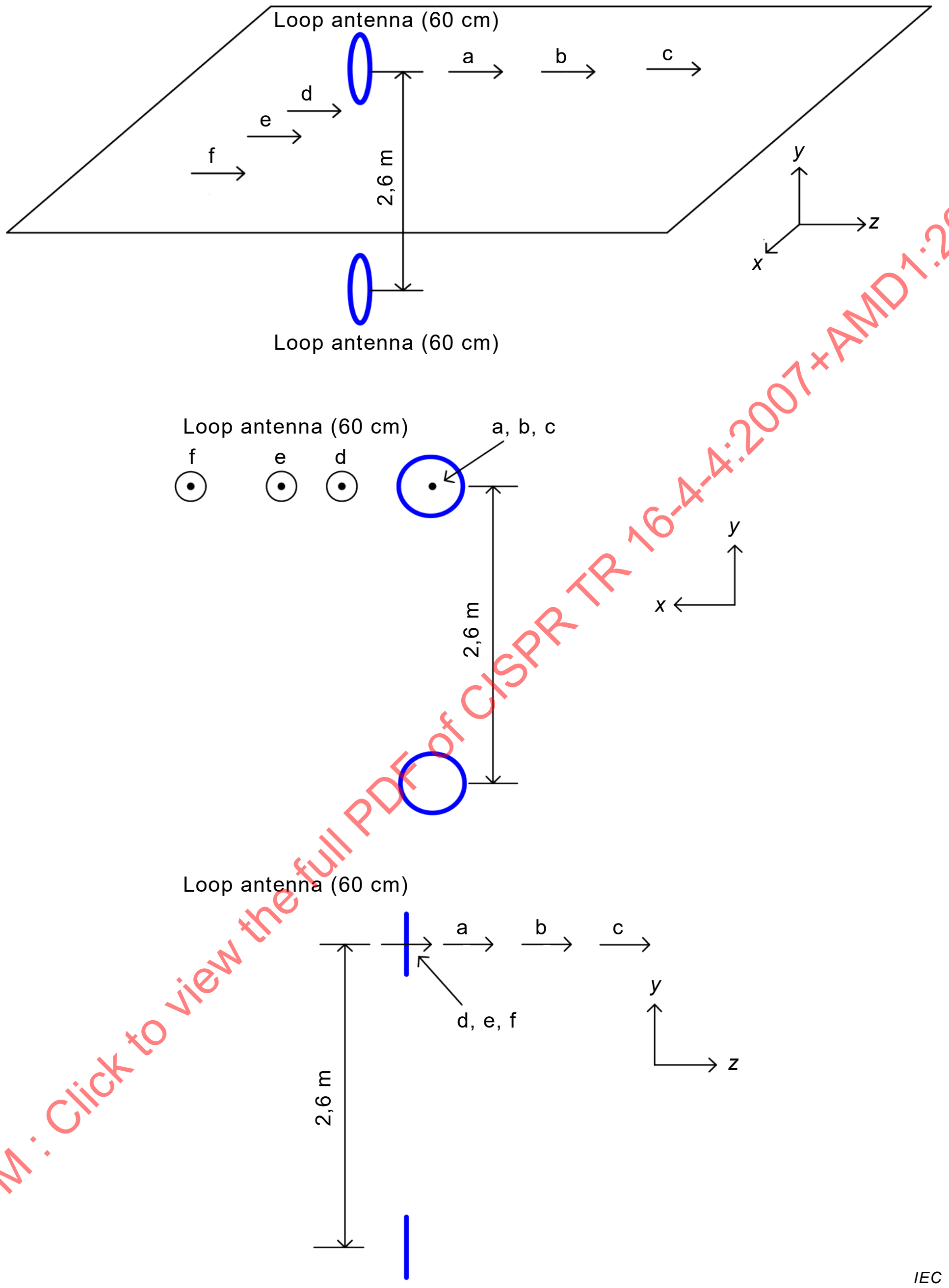


Figure B.2 – Commercial tool model for the application of image theory

Figure B.3 shows the scene of OATS where measurement is carried out at 1,3 m height from the centre of the antenna with 3 m distance between antennas at coaxial and coplanar direction, respectively.

a) **Measurement at coaxial direction at 3 m**　　b) **Measurement at coplanar direction at 3 m**

Figure B.3 – Photos of OATS measurement setup

Figure B.4 is a graphical presentation which allows us to compare the results from a simulation both at coaxial and coplanar directions where the ground plane using a commercial tool is included and where image theory has been applied. It suggests that the simulation result from each model almost agrees.

Figure B.5 presents comparison results between the H-field conversion factors determined by using commercial tools and measurement data.

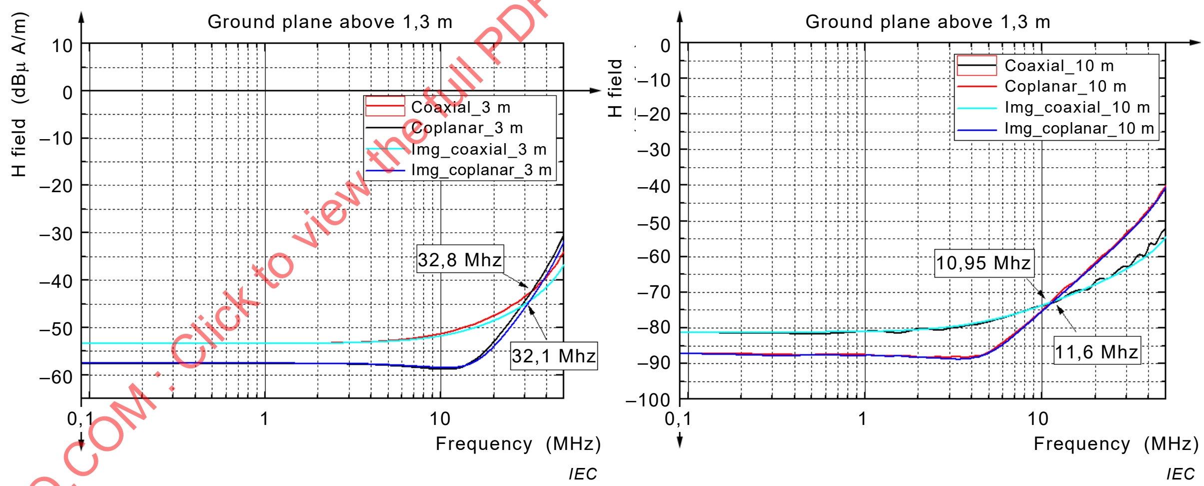


Figure B.4 – Comparative simulation result with ground plane and with image theory

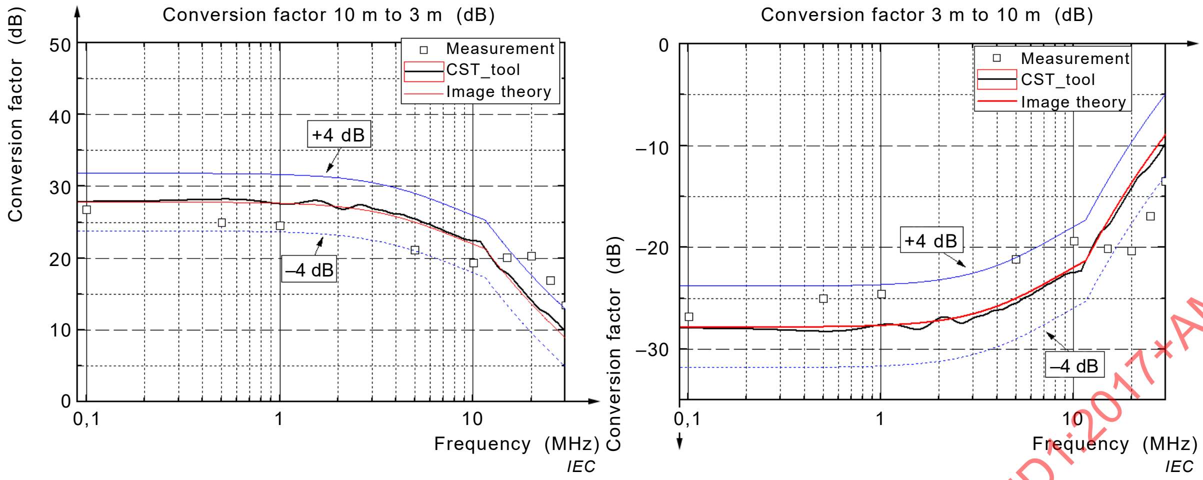


Figure B.5 – Comparison between the simulated conversion factors and the measurement results

B.2 H-field conversion factors obtained from simulation results

The conversion factors of measurement distances of 3 m and 10 m are derived from the measurement distance of 30 m under the test environment with the ground plane for H-field measurement.

The H-field limit in dBµA/m at 3 m, H_{3m}, is determined from H_{30m} by the following equation:

$$H_{3m} = H_{30m} + C_{3\_min} \quad \text{(B.1)}$$

where

H_{30m} is the H-field limit in dBµA/m at 30 m distance;

C_{3_min} is a conversion factor in dB as shown in Figure B.6 and Table B.1

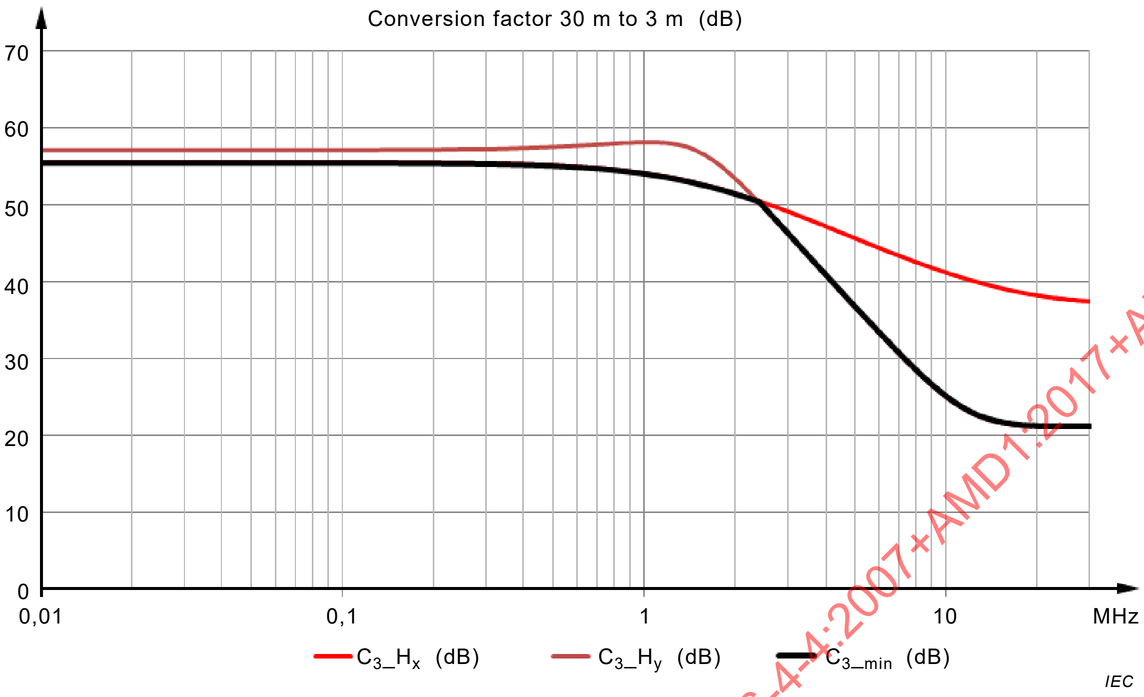


Figure B.6 – Conversion factor C_{3_min}

Table B.1 – Conversion factor C_{3_min}

Frequency MHz	$C_{3}\_H_x$ dB	$C_{3}\_H_y$ dB	C_{3_min} dB
0,01 (or 0,009)	55,3	57,2	55,3
0,15	55,5	57,3	55,5
1	54,1	58,2	54,1
2	51,5	53,6	51,5
2,4	50,5	50,5	50,5
3	49,1	46,3	46,3
5	45,7	36,7	36,7
10	41,2	25,1	25,1
11	40,7	23,9	23,9
12	40,3	23,0	23,0
13	39,9	22,4	22,4
14	39,5	22,0	22,0
15	39,3	21,7	21,7
20	38,3	21,2	21,2
30	37,5	21,1	21,1

The H-field limit in dBµA/m at 10 m, H_{10m}, is determined from H_{30m} by the following equation:

$$H_{10m} = H_{30m} + C_{10\_min} \quad \text{(B.2)}$$

where

H_{30m} is the H-field limit in dBµA/m at 30 m distance;

C_{10_min} is a conversion factor in dB as shown in Figure B.7 and Table B.2.

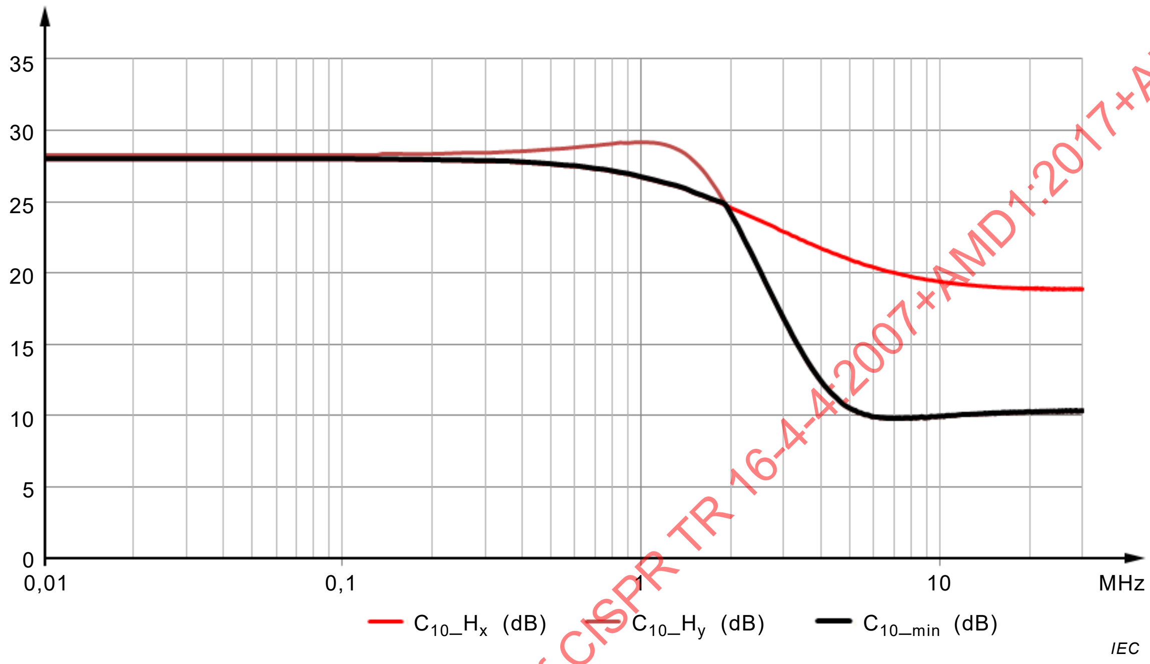


Figure B.7 – Conversion factor C_{10_min}

Table B.2 – Conversion factor C_{10_min}

Frequency MHz	$C_{10}–H_x$ dB	$C_{10}–H_y$ dB	C_{10_min} dB
0,01 (or 0,009)	28,0	28,3	28,0
0,10	28,0	28,3	28,0
0,15	28,0	28,3	28,0
0,2	27,9	28,3	27,9
0,3	27,9	28,4	27,9
0,4	27,8	28,5	27,8
0,5	27,7	28,7	27,7
0,6	27,5	28,8	27,5
0,7	27,3	28,9	27,3
0,8	27,2	29,0	27,2
0,9	27,0	29,1	27,0
1	26,7	29,1	26,7
1,9	24,8	24,9	24,8
2	24,6	24,1	24,1
3	22,9	16,7	16,7
5	21,0	10,5	10,5
10	19,4	9,9	9,9
20	19,0	10,3	10,3
30	18,9	10,3	10,3

The H-field limit in dBµA/m at 3 m, H_{3m}, can be also determined from H_{10m} by the following equation:

$$H_{3m} = H_{10m} + C_{10\text{-}3\_min} \qquad (B.3)$$

where

H_{10m} is the H-field limit in dBµA/m at 10 m distance;

$C_{10\text{-}3\_min}$ is a conversion factor in dB as shown in Figure B.8 and Table B.3.

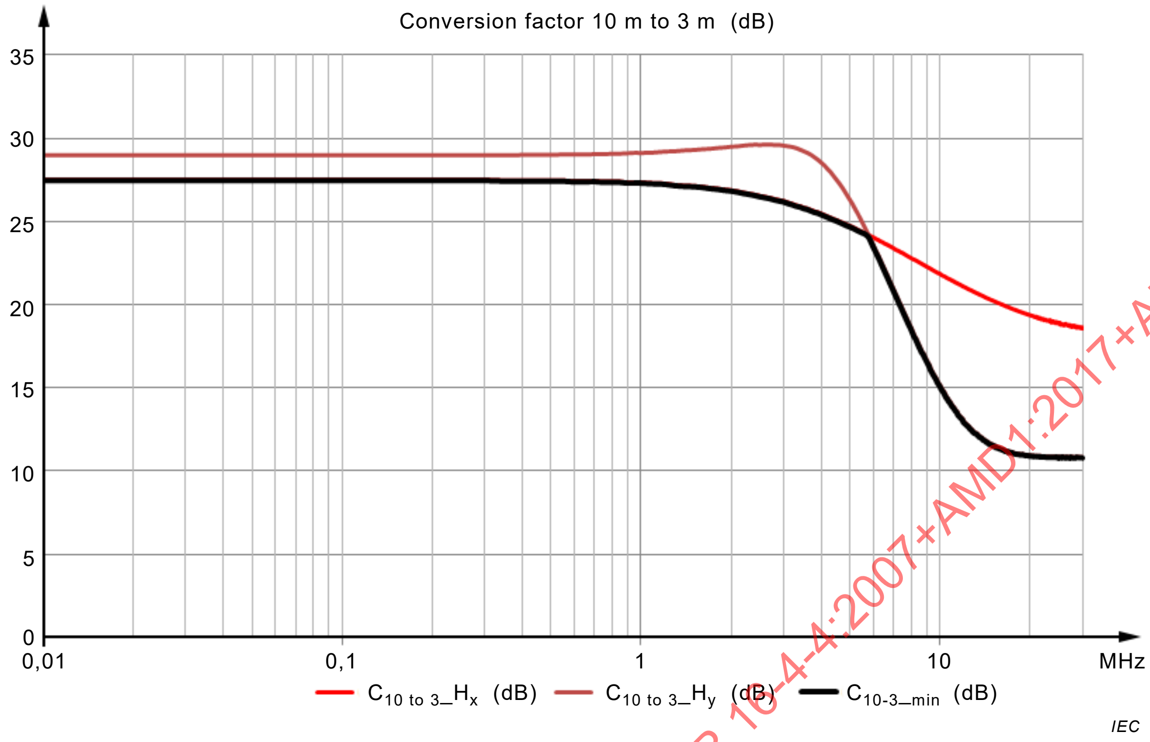


Figure B.8 – Conversion factor $C_{10\text{-}3\_min}$

Table B.3 – Conversion factor $C_{10\text{-}3\_min}$

Frequency MHz	$C_{10\ to\ 3}\text{–}H_x$ dB	$C_{10\ to\ 3}\text{–}H_y$ dB	$C_{10\text{-}3\_min}$ dB
0,01 (or 0,009)	27,5	29,0	27,5
0,15	27,5	29,0	27,5
1	27,4	29,1	27,4
2	26,9	29,5	26,9
3	26,2	29,6	26,2
5	24,7	26,2	24,7
5,8	24,2	24,1	24,1
10	21,8	15,1	15,1
11	21,4	13,9	13,9
12	21,1	13,0	13,0
13	20,7	12,3	12,3
14	20,5	11,9	11,9
15	20,0	11,6	11,6
20	19,3	10,9	10,9
30	18,6	10,8	10,8

B.3 Recommended conversion factors of H field limits for measurement distances

B.3.1 General

The recommended conversion factors from the simulated results for use of product committee are given in the following subclauses.

B.3.2 Recommended conversion factor for the limit of H-field from 30 m to 3 m, $CF_{30m\ to\ 3m}$

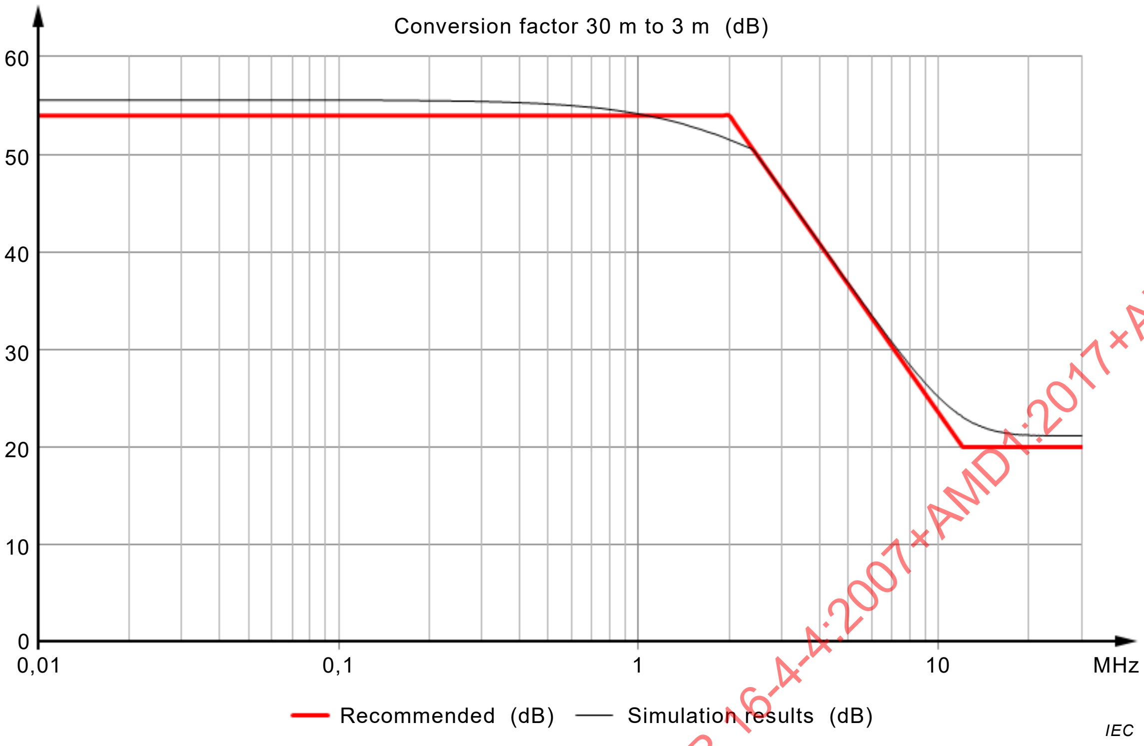


Figure B.9 – Recommended conversion factor $CF_{30m\ to\ 3m}$

Table B.4 – Recommended conversion factor $CF_{30m\ to\ 3m}$

Frequency MHz	$CF_{30m\ to\ 3m}$ dB
0,01 (or 0,009)	54
2	54
2 to 12	linearly decreased 54 to 20 [y = -(43,69) × log(x)+ 67,15]
30	20

B.3.3 Recommended conversion factor for the limit of H-field from 30 m to 10 m, $CF_{30m\ to\ 10m}$

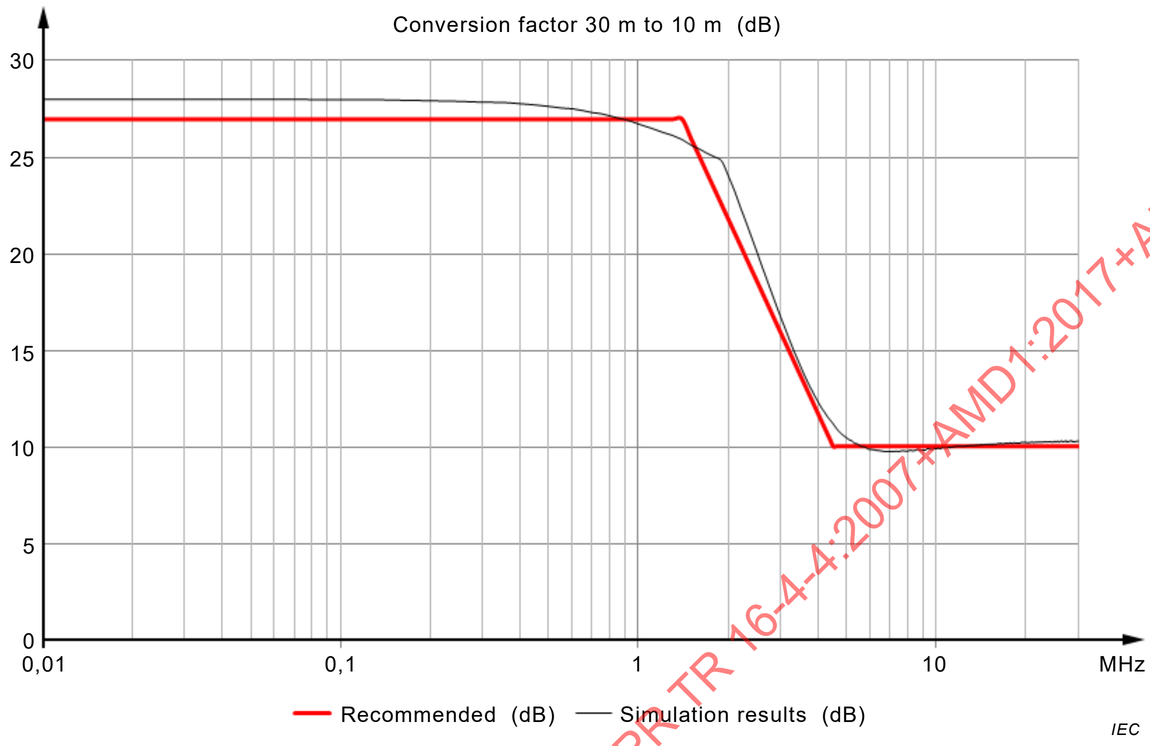


Figure B.10 – Recommended conversion factor $CF_{30m\ to\ 10m}$

Table B.5 – Recommended conversion factor $CF_{30m\ to\ 10m}$

Frequency MHz	$CF_{30m\ to\ 10m}$ dB
0,01 (or 0,009)	27
1,5	27
1,5 to 4,5	linearly decreased 27 to 10 [y = -(33,52] × log(x)+ 32,90]
30	10

B.3.4 Recommended conversion factor for the limit of H-field from 10 m to 3 m, $CF_{10m\ to\ 3m}$

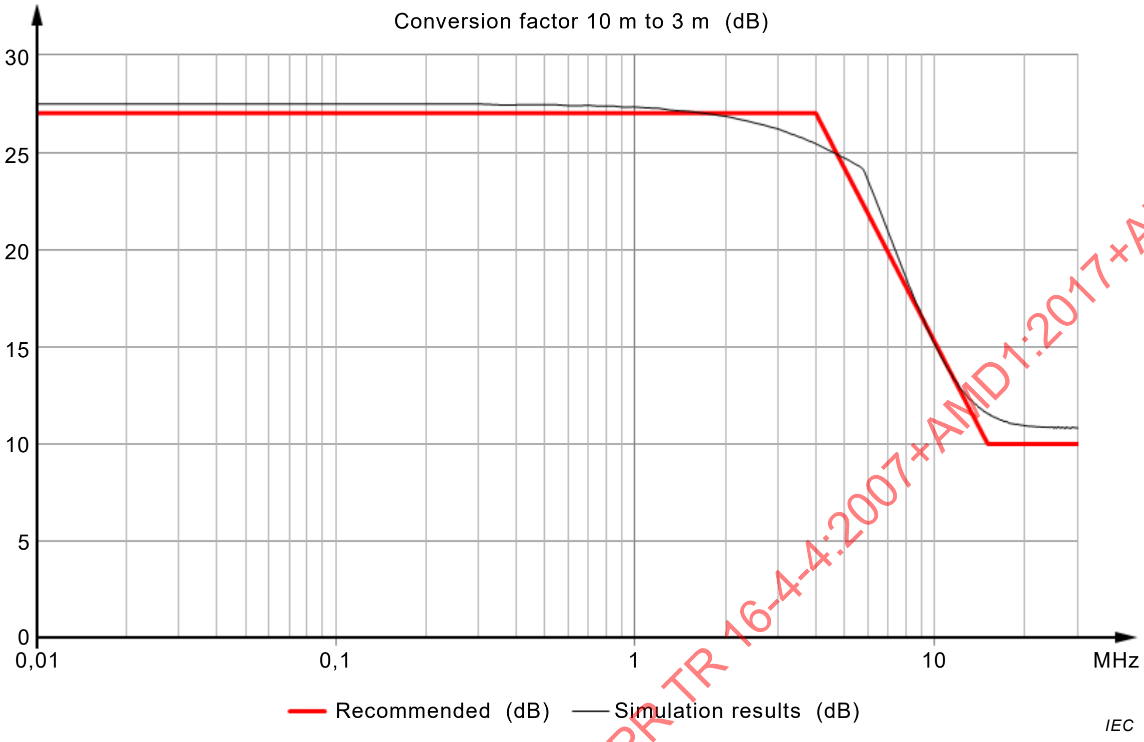


Figure B.11 – Recommended conversion factor $CF_{10m\ to\ 3m}$

Table B.6 – Recommended conversion factor $CF_{10m\ to\ 3m}$

Frequency MHz	$CF_{10m\ to\ 3m}$ dB
0,01 (or 0,009)	27
4	27
4 to 15	linearly decreased 27 to 10 [y = -(29,62] × log(x)+ 43,83]
30	10

Annex C
(informative)

Model for estimation of radiation from photovoltaic (PV) power generating systems

C.1 Overview

This annex presents a model for the estimation of radiation from photovoltaic (PV) power generating systems in the radio frequency range. The model is based on theoretical assumptions, measurement and simulation results as well as on a database with the statistical values of relevant parameters together with appropriate model factors. The simulation results were validated by measurement.

The model was developed for verification of the limits for the LV DC power port of power converters (GCPCs) intended for assembly into PV power generating systems specified in CISPR 11.

The subject of interest was the frequency range below 30 MHz and PV generators with a nominal power throughput in the range up to 20 kVA. Of the two known modes of conducted disturbances, radiation caused by conducted common mode (CM) disturbances was found to be dominant. Therefore the model exclusively considers radiation caused by common mode RF currents (i.e. antenna mode currents).

The structure of this annex is divided into two main parts.

Clause C.2 describes the general model approach mainly consisting of physical rationale, formulae and procedural methods needed for the characterization of the interrelation of the relevant influence factors.

The approach is based on the application of practical data for the various model input parameters gained from measurement, simulation and statistics. Clause C.3 provides the calculation of a resulting limit which serves the primary task of verification of the limits for the LV DC power port of power converters specified in CISPR 11.

C.2 Description of the basic model

C.2.1 Overview

To provide a model suitable for an estimation of radiation from photovoltaic (PV) power generating systems, various influence factors have to be considered.

Figure C.1 gives a schematic overview of the determined influence parameters considered in the model and their interrelation.

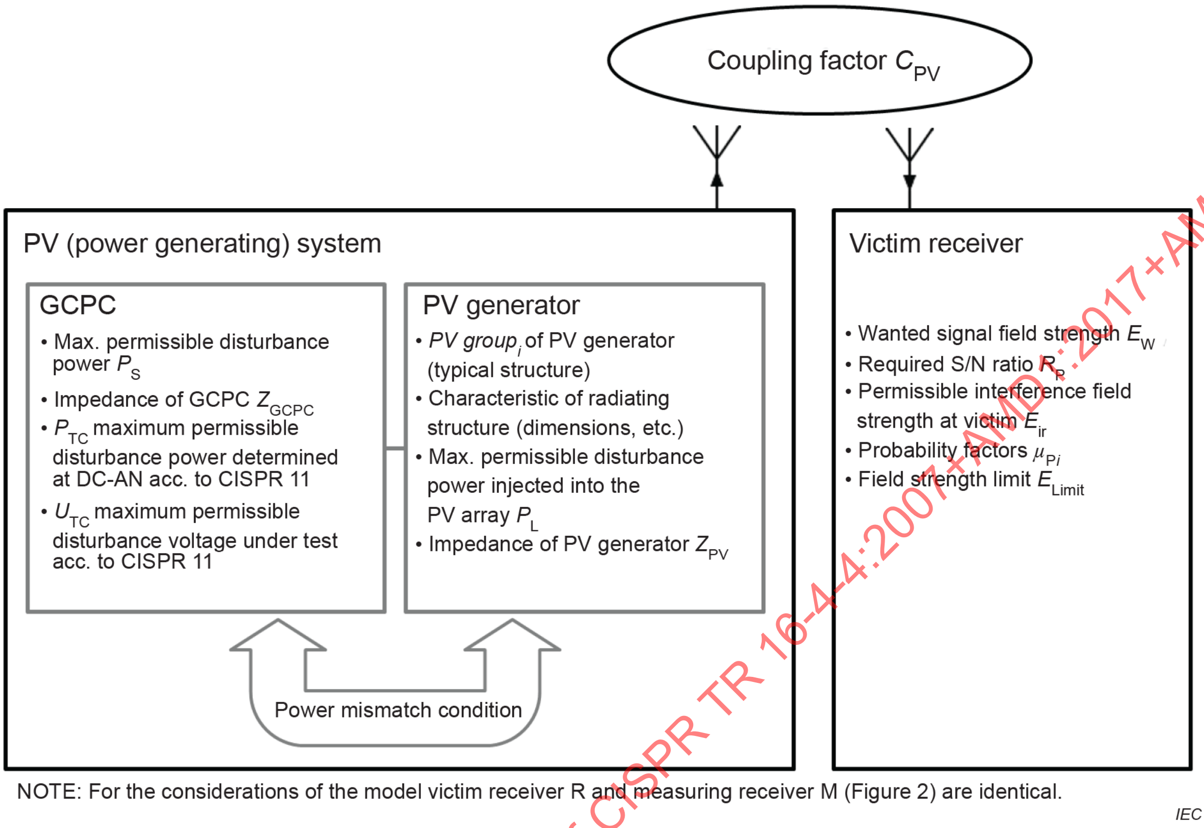


Figure C.1 – Schematic overview of the considered model influence factors

Initially, the permissible value for the disturbance field strength limit E_{Limit} was determined, at a given point A in space where the antenna of the victim receiver is located, with help of the given formula for the mathematical interrelation of relevant parameters in a remote coupling situation (see C.2.2).

In a second step a model for the PV power generating system was introduced to determine the RFI potential. Subsequently, typical classes of PV power generating systems were selected. Sets of appropriate input parameters for modelling the radiation characteristics were determined (see C.2.3). Those input parameters comprise all the mechanical and electrical data of the solar generator used during its simulation, including electrical permittivity and conductivity of the surrounding ground.

Based on these conventions and assumptions, the coupling between the electromagnetic field at the victim receiver location and the PV generator was characterized by a parameter (introduced as coupling factor C_{PV}). By means of the field strength limit E_{Limit} and this coupling factor C_{PV} the maximum permissible disturbance power P_L injected into the PV generator was estimated. Thereby the basic model for the PV power generating system was completed (see C.2.4).

In addition, the effects of power mismatch losses in test site conditions and at the place of operation of PV power generating systems were used to refine the model (see C.2.5).

C.2.2 Conditions at the location of the antenna of the victim receiver

Considering the technical parameters for reliable transmission and reception of the radio service or application to be protected, the permissible interference field strength E_{ir} (without consideration of probability factors) at the point A in space where the antenna of the victim receiver is located can be determined by subtracting the necessary protection ratio R_P from the minimum wanted field strength E_w needed for this radio reception (see Equation (C.1), all quantities expressed in logarithmic units).

$$E_{ir} = E_w - R_P \quad (C.1)$$

The permissible interference field strength is based on the measurement bandwidth of 9 kHz for the frequency range in question used together with the limit. If the radio service evaluated uses the same bandwidths, as in the case of broadcast radio, no change is necessary. If however the bandwidth of the victim radio service is lower than the measurement bandwidth, a correction shall be applied according to 5.6.6.2 (see Equation (C.2)).

$$E_{ir,corr} = E_{ir} + 10 \times \log\left(\frac{b_{victim}}{b_{measurement}}\right) \quad (C.2)$$

When the calculation of limits for the DC power port of a power converter (GCPC) intended for assembly into a PV power generating system is considered, then only the radiation coupling path to the victim radio receiver needs to be considered. The conductive coupling via the LV AC mains lines is considered to be highly unlikely due to heavy filtering of the AC mains power port of the GCPC.

Equation (37) of this document is the basic calculation rule to gain the permissible disturbance field strength limit E_{Limit} for use with type tests on standardized test sites. The comprehensive formula also includes the various probability factors μ_{Pi} and their corresponding standard deviations σ_{Pi}, reflecting the likelihood of occurrence of a real disturbance in the field, as well as the term $t_\beta \sigma_i$ describing the predefined statistical significance of CISPR limits for type-approved appliances. Combining Equation (37), Equation (C.1) and Equation (C.2) leads to Equation (C.3):

$$E_{Limit} = E_{ir,corr} + \mu_{P1} + \ldots + \mu_{P10} + t_\beta \sigma_i - t_\alpha \sqrt{\sigma_{P1}^2 + \ldots + \sigma_{P10}^2} \quad (C.3)$$

NOTE 1 Suitable probability factors for PV power generating systems are defined depending on the context of application (see C.3.3).

NOTE 2 This document is based on the assumption that the signal characteristics of disturbances caused by PV systems in its worst case are continuous, leading to equivalent outputs of all CISPR detectors.

Once the field strength limit E_{Limit} is found, a coupling factor C_{PV} comprising the coupling characteristics between the electromagnetic field at the victim receiver location and the PV power generating system can be applied to estimate the maximum permissible disturbance power P_L that can be injected into a given PV generator (see C.2.4).

C.2.3 Characteristics of PV generators

C.2.3.1 General

In this Subclause C.2.3 a model for the PV power generating system is introduced to determine the permissible RFI potential. Subsequently, typical classes of PV power generating systems are selected. Sets of appropriate input parameters for modelling of their radiation characteristics are determined.

C.2.3.2 Characteristic parameters of a PV generator seen as radiator of RF disturbances

In a simplified approach, a typical PV power generator can be regarded as an ideal vertical rod antenna with capacitive top loading. The DC power string wires are treated as antenna, while the PV panels or modules make up its capacitive loading. This approach is applicable for common mode radiation only, but several investigations indicated this radiation to be predominant in the considered case.

For the specified power range (i.e. up to 20 kVA) typical PV generator configurations can be found in large numbers. On a single-family detached house some PV panels are mounted on the inclined roof. For multiple-family houses very often a flat top roof can be found carrying rows of PV panels on its top. A sun tracker, which is made up by a singular steel support carrying some PV panels that always present their broad side to the sun, and fairly large generators on barns in the countryside, are also fairly common.

As consideration of every individual PV generator configuration is not feasible, group representatives of PV generator types are introduced (see C.2.3.3).

Subclause C.3.4 reveals the technical parameters that were assumed and used in the simulation for calculation of the RF characteristics of the respective group of PV generators.

C.2.3.3 Grouping of PV generators

For every individual photovoltaic power generating system or installation, the individual coupling property C_{PV_i} may assume a different value, but it can be expected that PV generators with about the same geometric structure and size, will show a typical property C_{PV_i} allocated somewhere in a given (predictable standard deviation) range.

As PV generators occur in various different configurations in the field, it was decided to define group representatives of PV generator types and to create a model for each group leading to different coupling factors $C_{\mathrm{PV\ Group}\ i}$ (see C.3.4), describing the interrelation between the victim receiver and the respective assumed group or category of PV generators.

The defined PV generator groups are:

Group A – Single-family detached houses;

Group B – Multi-storey buildings with flat roof tops;

Group C – Sun tracking supports (“trees”);

Group D – Large barns in the countryside.

Assuming the properties of all photovoltaic power generators in the world are known and that every individual one of those can be put into one of the predefined groups which is represented by its model or type (and thus has C_{PV_i} as a describing constant) it can be defined that

$$\rho_i = \frac{\text{Nb of PV generators in group } i}{\text{Nb of PV generators in the world}} \qquad \text{(C.4)}$$

where ρ_i represents the probability of an individual PV generator being a member of group i, while the respective coupling factor C_{PV_i} describes the typical RF characteristics of this group (see Figure C.2).

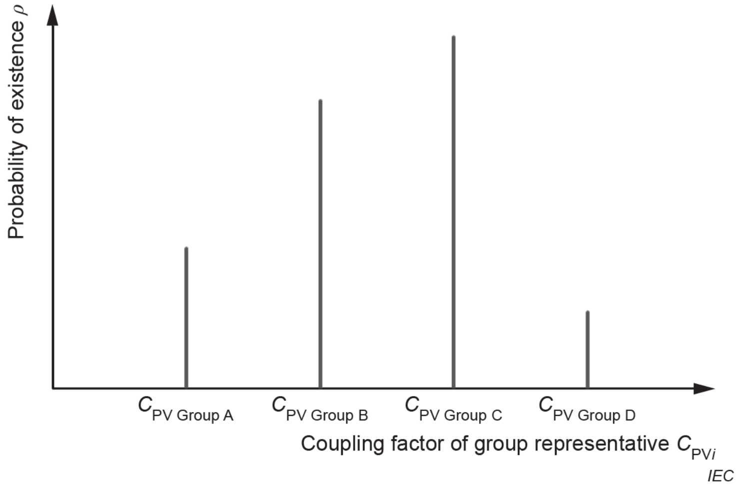


Figure C.2 – Schematic representation of probability of existence of PV generator groups in the field

Statistical data on the population density of the PV generators in the field is given in C.3.4.3.2.

From this data, a group-independent mean value for the coupling factor $\overline{C}_{\text{PV}}$ and its variance $\overline{\sigma}_{\text{PV}}$, which is valid and typical for any PV generator configuration, can be deduced (see Figure C.3).

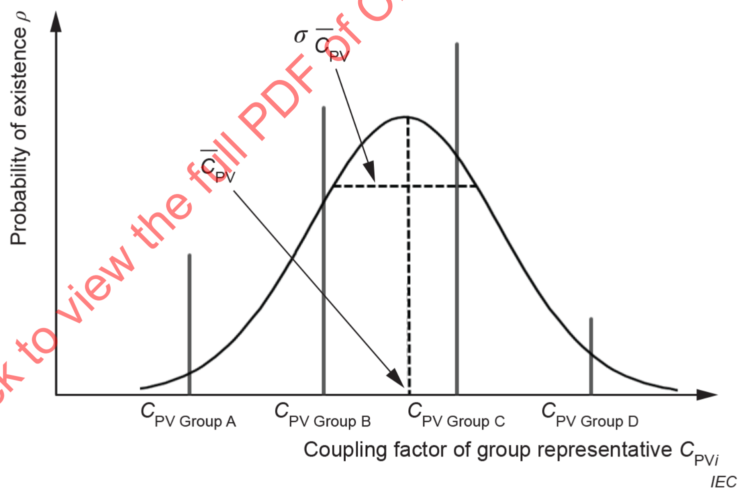


Figure C.3 – Schematic representation of mean value $\overline{C}_{\text{PV}}$ and variance σ_{CPV}

The global (or mean) value $\overline{C}_{\text{PV}}$ can be calculated by Equation (C.5):

$$\overline{C}_{\text{PV}} = \sum_{\text{all groups}} C_{\text{PV}} \times \rho_i \qquad \text{(C.5)}$$

This simplified value $\overline{C}_{\text{PV}}$ for the global coupling factor is needed to select the type-independent limit $U_{\text{TC Limit}}$ for the LV DC power port of power converters (GCPCs) specified in CISPR 11 (see Clause C.3 of this document).

C.2.3.4 Electrical input parameters of the PV generator

One intermediate step of the approach is the determination of the maximum permissible disturbance power P_L that may be injected into the PV generator. In power matching conditions, this P_L is identical with the permissible disturbance power P_S provided by the GCPC.

For thorough estimation of the RFI potential, the typical power mismatch loss between the GCPC and the DC power interface of the respective PV generator has to be taken into account which requires knowledge of the complex impedances of GCPCs and PV generators (see C.2.5).

C.2.4 Coupling between the electromagnetic field at the victim receiver location and PV power generating system

C.2.4.1 General

When assessing the disturbance potential of any given apparatus with any attached structure, the relationship between the disturbance field strength E_{Limit} at a given point A in space and the RF power P_L fed into the radiating structure by the given apparatus has to be determined. The relevant technical parameter or characteristic of a given PV generator is its frequency dependent coupling factor C_{PV}.

For this task, the disturbance source, i.e. the grid connected power converter (GCPC) can be modelled as a common mode power generator that injects a certain power P into a radiating structure through its DC power port. The AC power port connects directly or via the PE conductor in the AC mains cable local ground as the counterpoise of the radiating structure. A block scheme covering this situation is shown in Figure C.4.

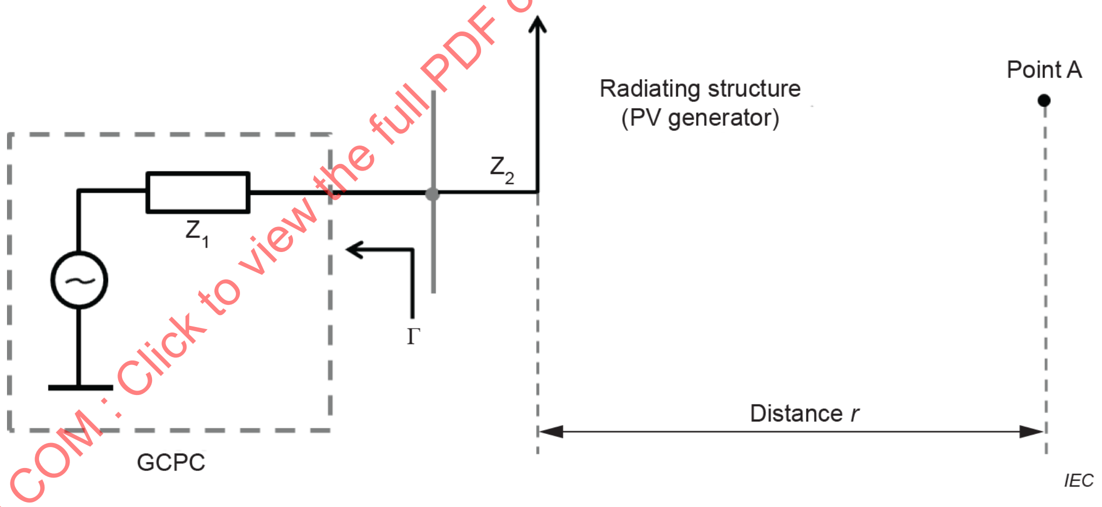


Figure C.4 – General model for coupling of CM disturbances of a GCPC to an attached photovoltaic power generating system (PV generator)

In a first approach the observation point A in space is assumed to be located at a fixed distance r from the PV generator. The electrical (disturbance) field strength E of the electromagnetic field emanating from the radiating structure is proportional to the square root of the real power P fed into the PV generator, due to the linearity of Maxwell's equations.

For a single point in space, a fixed function $C_{PV} = C_{PV}(f)$ (coupling factor) describes the proportionality of the field strength E with the square root of the power P injected into the radiating structure by the apparatus (GCPC), as given in Equation (C.6).

$$E = C_{PV} \times \sqrt{P} \qquad (C.6)$$

For EMC considerations the situation at a fixed distance (e.g. the CISPR protection distance of 10 m or 30 m) is needed. For real objects many points in space with the property of having a given distance to the EUT exist, for example in different azimuth directions and at different heights. This applies to simulation and measurement equally. Therefore the field strength used in Equation (C.6) shall undergo some kind of maximization procedure before being used for the calculation of the coupling factor. Henceforward this parameter C_{PV} covers the worst case radiation properties/characteristics of the model for the fixed installation and is explicitly valid for one given fixed distance r and one specific group (A, B, C or D) of PV generators. By means of Equation (C.7) the maximum permissible disturbance power that may be injected into the PV generator P_L can be calculated to:

$$P_L = \frac{E_{Limit}^2}{C_{PV}^2} \qquad (C.7)$$

Basically, it does not matter whether a victim receiver's antenna picks up either the electric or the magnetic portion of the radiated disturbance and which of the two coupling mechanisms is predominant for the respective distance. They differ, because for most frequencies the victim receiver is in the near field zone of the radiating structure.

Using the coupling factor for the electric field strength and the magnetic field strength to calculate the resulting field strengths appearing at the point in question, it can be seen, that the two coupling factors can be compared to each other in the same unit (Equation (C.8)). The disturbance field strengths, which are compared to each other and to the field strength of the radio service, are in the far field of the transmitter.

$$\left.\begin{aligned} E &= C_{PV\,elec} \cdot \sqrt{P} \\ H &= C_{PV\,mag} \cdot \sqrt{P} \end{aligned}\right\} \rightarrow \frac{E}{H} = \frac{C_{PV\,elec}}{C_{PV\,mag}} \qquad (C.8)$$

By multiplying the coupling factor for the magnetic field $C_{PV\,mag}$ with the free space impedance Z_0, the results can be compared in the same units. Note that the coupling factor for the magnetic fields will also be given in the unit $\sqrt{\Omega}/\mathrm{m}$ (see Equation (C.9)).

$$C_{PV\,elec}\left[\frac{\sqrt{\Omega}}{\mathrm{m}}\right] = C_{PVmag}\left[\frac{1}{\mathrm{m}\cdot\sqrt{\Omega}}\right] \cdot Z \qquad (C.9)$$

NOTE Generally electric and magnetic fields are not interrelated by the free space impedance Z_0 in the near field.

By convention, the coupling factor for the required protection distance is defined as the mean value of all field strengths determined for a number of points in the xy-plane at the required distance. When only four spatial directions are assessed, the final values of the coupling factor can be calculated by

$$\begin{aligned} C_{PV\,elec} &= \mathrm{mean}(C_{PV\,elec\,0°}, C_{PV\,elec\,90°}, C_{PV\,elec\,180°}, C_{PV\,elec\,270°}) \\ C_{PV\,mag} &= \mathrm{mean}(C_{PV\,mag\,0°}, C_{PV\,mag\,90°}, C_{PV\,mag\,180°}, C_{PV\,mag\,270°}) \end{aligned} \qquad (C.10)$$

In a last step the predominant coupling (electric or magnetic) is found by maximization.

$$C_{PV} = \max(C_{PV\ elec}, C_{PV\ mag} \times Z_0) \qquad (C.11)$$

C.2.4.2 Determination of coupling factor by simulation $C_{PV\ sim}$

One approach to determine the coupling factor is to carry out simulations with a Maxwell equation solver (i.e. NEC2, FEKO, Concept).

Taking a defined representative geometrical configuration for each PV generator group as basis, a relationship between the injected disturbance power and the resulting radiated disturbance field strength in a point A in space at a defined distance from the PV generator can be found.

The main input for the simulation is the geometry of the photovoltaic generator. This mechanical structure needs to be programmed into the simulating engine. An example is shown in Figure C.5.

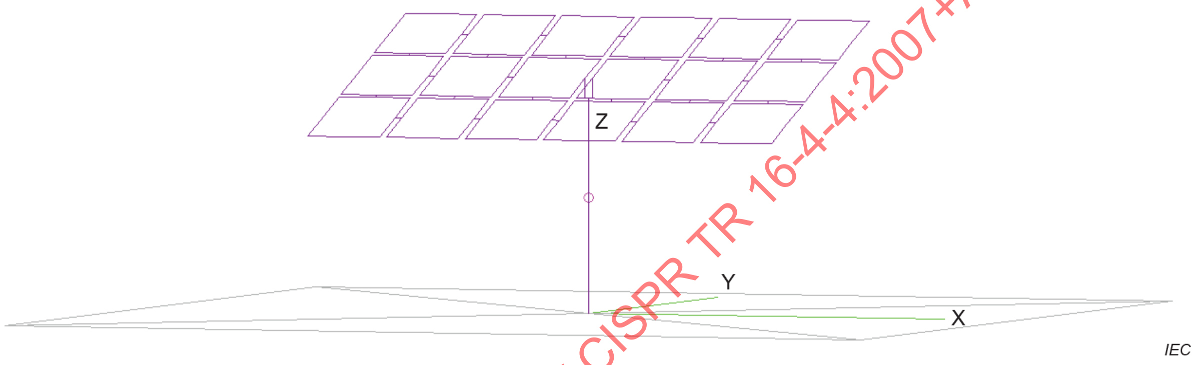


Figure C.5 – Geometric representation of a PV generator with 18 modules

In the defined structure, common mode power is injected at the feed point (indicated by a purple circle in the middle of the feed line) and the field strength is calculated in a cuboid around the structure. The distance from the structure at which the coupling factor C_{PV} shall be calculated determines the size of the cuboid in x and y directions. The protection distance in CISPR standards is often 3 m, 10 m or 30 m. For a large structure like a photovoltaic array, calculations for the protection distance of 3 m are not used for the example presented in this document. The size of the cuboid in vertical z direction shall be twice the height of the structure itself.

The output of the simulation is the field strength on the surface of the pre-programmed cuboid. Choosing a point on the xy-plane at a distance corresponding to the required protection distance defines a vertical line (see Figure C.6).

Dimensions in metres

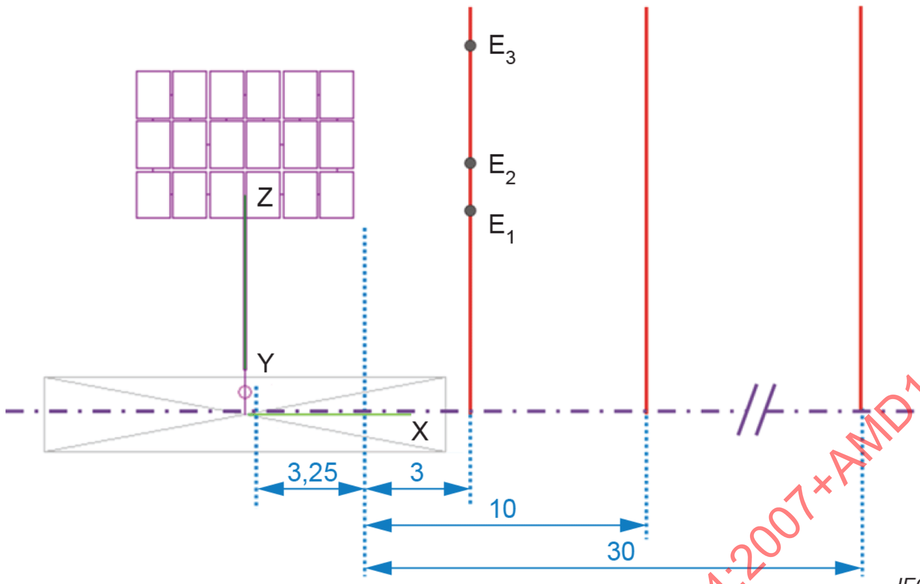


Figure C.6 – Field strength determination by maximization (height scan) along a red line

The maximum of all field strengths in the cross-section between this line and the cuboid represents the final field strength for the distance. Ideally this procedure would be repeated for each angular direction, however it suffices to consider only the four different orthogonal directions in space. The coupling factor $C_{PV\ sim}$ is then derived according to Equations (C.10) and (C.11).

C.2.4.3 Determination of coupling factor by measurement $C_{PV\ meas}$

The coupling factor introduced by Equation (C.6) can also be determined by measurement. However, as the coupling factor is defined in transmission mode, it is difficult to measure the field strength distribution around a typical setup for a PV generator, since the setup is too large for accurate measurement in most available shielded rooms. On the other hand it is not possible to actually transmit a potential test signal on any frequency at the installation site of a PV generator, because of national restrictions. However, under specific operating conditions (e.g. limitation of transmission to suitable single test frequencies) a measurement on real installations is feasible.

For these measurements, the DC wires of the PV generator shall be disconnected from the GCPC, shorted and connected to a typical antenna tuner. The tuner should be grounded the same way an installed GCPC would be grounded. The tuner shall be able to tune the feed point impedance of this “antenna” to the 50 Ω output of the transmitter at all test frequencies, such that only very little RF reflection occurs. The actual forward and reflected power shall be measured and monitored during the procedure with a power meter.

The field strength shall then be measured at a pre-defined fixed distance from the outer boundary of the PV installation (e.g. at 10 m or 30 m). The measurement should be made in the four dominant perpendicular directions at heights starting from 1 m above ground level up to twice the installation height. If this cannot be achieved, the measurement can be simplified to fewer directions and lower and fewer heights.

A comprehensive result table of this suite of measurements shall provide the following information:

1) frequencies used for testing;

2) location (distance *r* from the boundary of the PV generator, orientation in 90° angles and height above ground);
3) forward and reflected power to determine the radiated power P_L (power mismatch considered);
4) total electric and magnetic field-strength (derived from the *x*, *y*, and *z* components);
5) ambient noise level of electric and magnetic field strength;
6) determined maximum value of the field strength reading obtained in each height;
7) determined mean of the measured field strength values E_{meas} and H_{meas}, between for example the four perpendicular directions used for the measurements;
8) evaluation result: maximum of measured coupling factors $C_{PV\ elec\ meas}$ and $C_{PV\ mag\ meas}$.

The respective coupling factors can be calculated from the test results by means of Equations (C.10) and (C.11).

C.2.4.4 Validation of simulation results with measurements

Comparison of measurement and simulation results will always show discrepancies. On the one hand reasonable simulation does not seek to reproduce reality completely (input parameters will be simplified or in some cases will not be sufficiently known), but focusses on the assumed main influence factors. On the other hand, measurements are also influenced by unwanted factors (uncertainty characteristics of the test equipment, environmental influences in situ, limited height scan capabilities, access problems in different azimuth directions, etc.), especially in the case of the complex test setup referred to in this annex.

To check and increase the accuracy of the simulation, measurements on several PV generator structures shall be performed to verify the simulation results (see C.3.4).

C.2.5 Considerations of power mismatch losses

C.2.5.1 General

Subclause C.2.5 contains mathematical considerations regarding the usual power mismatch conditions between the PV generator and the GCPC at the installation site of the PV generator.

In addition, the power matching conditions between the GCPC and the DC-AN in the test case according to CISPR 11 can be considered. This allows conclusions to be drawn from ordinary GCPC type test data about the maximum disturbance power P_S of the GCPC deliverable in a given installed PV generator.

Due to the representation of test site conditions (Equation (C.15)) in the measurement uncertainty and the lack of the representation of the relationship between the maximum permissible power in the test case and in the installation case (Equation (C.16)) in any other investigations (e.g. radiation from AC mains grid networks), this option can be added if this scenario type is required. But then the related factors, for example measurement uncertainty or AC mains, grid investigations and limits may have to be adjusted in a similar way.

C.2.5.2 Power mismatch conditions at the installation site of the PV power generating system

In practice there is a certain loss of power compared to power matching conditions between source and load, when the source of RF disturbances, in this case the PV power converter (GCPC), is connected to an RF load, in this case the installed PV generator.

This quantity is denoted as the mismatch loss m_L and can be considered as a real attenuation. For a GCPC with the complex source impedance Z_S emitting a disturbance power

P_S into the PV generator with the complex load impedance Z_L, the complex reflection coefficient Γ and the final loss can be calculated by Equation (C.12).

$$\Gamma = \frac{Z_L - \bar{Z}_S}{Z_L + Z_S}$$
$$m_L = 1 - |\Gamma|^2 \quad \text{(C.12)}$$
$$M_L = 10 \cdot \log\left(1 - |\Gamma|^2\right)$$

The actual power P_L injected into the PV generator, which is mainly radiated via that installation, is therefore reduced to (see Equation (C.13)):

$$P_L = m_L \cdot P_S \quad \text{(C.13)}$$

If P_L is known, then the maximum permissible disturbance power P_S that can be injected by the GCPC can be calculated with Equation (C.13).

Subclause C.3.6 gives some statistical data of impedances of PV generators (Z_L) and GCPCs (Z_S) to enable the determination of m_L.

C.2.5.3 Power mismatch conditions at the test site

In general, P_S will not be known, but can be derived from a measurement of P_{TC} on a standardized test site according to CISPR 11. The measurement impedance is fixed to Z_{TC} = 150 Ω, due to the technical parameters of the DC-AN, while the power converter still has the complex source impedance Z_S. Measuring P_{TC} in the test case (i.e. the disturbance power determined at the DC-AN) the unknown P_S can be calculated by

$$P_{TC} = m_{TC} \cdot P_S \quad \text{(C.14)}$$

with m_{TC} being described by

$$\Gamma_{TC} = \frac{150\,\Omega - \bar{Z}_S}{150\,\Omega + Z_S}$$
$$m_{TC} = 1 - |\Gamma_{TC}|^2 \quad \text{(C.15)}$$

C.2.5.4 Conclusion to test conditions

The relationship between the maximum permissible power in the test case P_{TC} and in the installation case P_L is given by the ratio of the two mismatch losses (Equation (C.16)):

$$\frac{P_{TC}}{P_L} = \frac{m_{TC}}{m_L} \quad \text{(C.16)}$$

The maximum permissible disturbance power P_S of the power converter (GCPC) is always higher than or equal to the measurement result in the test case, as both mismatch factors work one against the other. If the PV generator actually has an input impedance of 150 Ω, then m_{TC} and m_L are equal and cancel out.

If P_{TC} is known, the respective limit for the permitted disturbance voltage at the DC power port of the GCPC can be calculated using the following relation (Equation (C.17)):

$$U_{\text{Limit}}[\text{V}] = \sqrt{150\Omega \times P_{\text{TC}}[\text{W}]}$$
$$U_{\text{TC Limit}}[\text{dB}(\mu\text{V})] = 20 \times \log_{10}\left(\frac{U_{\text{Limit}}[\text{V}]}{1\mu\text{V}}\right) \quad (C.17)$$

C.3 Calculation based on practical values for the verification of the limits specified in CISPR 11

C.3.1 General

Clause C.3 presents a calculation based on practical values gained by measurement, simulation and statistical data for the introduced parameters of the model, to fulfil the primary task of the verification of the limits for the LV DC power port of power converters intended for assembly into PV power generating systems specified in CISPR 11.

The following list gives an overview of the parameters needed for the verification for a given radio service or application. The following subclauses will describe in detail the assumptions made to gain concrete values for the calculation.

- wanted signal field strength E_w;
- required S/N respectively protection ratio R_P;
- probability for time coincidence P_7;
- probability for location coincidence P_8;
- probability for frequency coincidence inclusive harmonics P_4;
- global coupling factor $\overline{C}_{PV}$;
- test site correction m_{TC};
- mismatch loss at installed PV generator m_L.

Some quantities, for example $t\alpha$ = 0,84 and $t\beta$ = 0,84 used in this Clause C.3 to calculate validation values in accordance with Clause C.2, are defined in the main clauses of this document. Furthermore σi, which describes the predefined statistical significance of CISPR limits for type-approved appliances, was set to zero, as the application of the 80/80-rule was discontinued.

C.3.2 Determination of the maximum permissible interference field strength E_{ir} at the location of the antenna of the victim receiver

The maximum permissible interference field strength E_{ir} for the disturbance is determined by subtracting the protection ratio from the wanted signal field strength of the radio application. Usually these parameters are given in ITU-R publications, but for simplicity CISPR has collected and published the results in the "Radio Services Database" on the IEC website under the EMC technology sector.

Here the radio application to be protected is chosen to calculate the permissible disturbance field strength E_{ir} by using Equation (C.1).

EXAMPLE A wanted signal field strength E_w = 44 dB(µV/m) and a necessary signal-to-noise or protection ratio R_P = 27 dB is taken, for good radio reception from a radio broadcast AM transmitter operating in the 31 m RF band.

This has to be evaluated for every entry in the radio services database resulting in a function for E_{ir} dependent on the frequency.

C.3.3 Probability factors

C.3.3.1 General

The disturbance will not actually occur in all cases, due to the fact that victim and source need to coincide in time, location and frequency. These three probability factors are assumed to play the major role in a disturbance scenario with a PV power generating installation.

When logarithmic probability factors are calculated, the linear probability shall be converted to a logarithm in base 10 and multiplied with a factor of 10, which originates from the signal-to-disturbance ratio defined as ratio of received signal power to the received disturbance power. Solely for distance ratios a factor of 20 shall be used.

C.3.3.2 Probability factor for time coincidence μ_{P7} and σ_{P7}

The disturbance can only occur at times, when the PV power generating system is in operation. The average day time is 12 h, but the production of energy is a bit less, due to mounting of the solar modules on an inclined plane. As an average of time 10 h are chosen, as the majority of installations are of this kind (Equation (C.18)).

$$\mu_{P7} = -10 \times \log_{10}\left(\frac{10}{24}\right) = 3{,}8 \text{ dB} \tag{C.18}$$

However, there are some other installation types also present, such as sun trackers or flat mounted modules. Therefore the “in operation” interval can vary in a wide range between 4 h and 20 h per day following an assumed uniform distribution that can be calculated by Equation (C.19):

$$\sigma_{P7} = -\frac{10 \times \log_{10}\left(\frac{20}{24}\right) - 10 \times \log\left(\frac{4}{24}\right)}{2 \times \sqrt{3}} = 2 \text{ dB} \tag{C.19}$$

C.3.3.3 Probability factor for location coincidence μ_{P8} and σ_{P8}

Conclusions on a representative probability factor for location coincidence were drawn based on data from Germany using information from the statistical data used for the determination of the coupling factor.

The value of 1,038 million photovoltaic installations registered combined with the amount of 40,96 million households (data status 2015) leads to a photovoltaic installation density of about 2,5 %. Taking into account future growth, a value of 1,6 million PV systems is taken as basis for the calculation leading to a density of 4 %. It is assumed that every house has four neighbours (front, rear, left and right) within the protection distance. However the total number of installations can vary (e.g. depending on other factors such as national funding), so photovoltaic installation densities in the field between 2 % and 8 % are assumed. Moreover, it is assumed that there is radio broadcast reception in every household.

These assumptions lead to Equation (C.20):

$$\mu_{\text{P8 PV}} = -10 \times \log_{10}(4 \times 0{,}04) = 8\ \text{dB} \tag{C.20}$$

$$\sigma_{\text{P8 PV}} = -\frac{10 \times \log_{10}(4 \times 0{,}02) - 10 \times \log_{10}(4 \times 0{,}08)}{2} = 3\ \text{dB} \tag{C.21}$$

However, there is only one amateur station in every thousand households in a world average. Therefore an additional location coincidence shall be applied in the case of the amateur radio service.

$$\mu_{\text{P8 AmaR}} = -10 \times \log_{10}(0{,}001) = 30\ \text{dB} \tag{C.22}$$

$$\sigma_{\text{P8 AmaR}} = -\frac{10 \times \log_{10}(0{,}0005) - 10 \times \log_{10}(0{,}005)}{2} = 5\ \text{dB} \tag{C.23}$$

C.3.3.4 Probability factor for frequency coincidence μ_{P4} and σ_{P4}

The frequency probability can be estimated by considering typical disturbance spectra of GCPCs.

Assuming that about 3 MHz out of the 30 MHz are occupied by emission, this leads to Equation (C.24):

$$\mu_{\text{P4}} = -10 \times \log_{10}\left(\frac{3}{30}\right) = 10\ \text{dB} \tag{C.24}$$

As the characteristic spectra of GCPCs vary across a broad range, a rather high uncertainty needs to be assigned, which leads to an assumption according to Equation (C.25):

$$\sigma_{\text{P4}} = 5\ \text{dB} \tag{C.25}$$

C.3.3.5 Maximum permissible field strength E_{Limit} considering probability factors

For every calculated E_{ir} according to C.3.2 the probability factors are applied using Equation (C.3) and result in a frequency dependent E_{Limit}.

EXAMPLE 1 In the case of the shortwave radio broadcast service in the 31-m-band introduced in C.3.2, with the wanted field strength of 44 dB(μV/m) and its protection ratio of 27 dB, taking into account the probability factors and their distributions (C.3.3.2 to C.3.3.4) a maximum permissible field strength of 33,6 dB(μV/m) can be calculated.

$$\begin{aligned} E_{\text{Limit}} &= E_{\text{W}} - R_{\text{P}} + \mu_{\text{P4}} + \mu_{\text{P7}} + \mu_{\text{P8}} + t_{\alpha} \cdot \sqrt{\sigma_{\text{P4}}^2 + \sigma_{\text{P7}}^2 + \sigma_{\text{P8}}^2} \\ &= \left(44 - 27 + 10 + 3{,}8 + 8 - 0{,}84 \cdot \sqrt{5^2 + 2^2 + 3^2}\right) \text{dB}(\mu\text{V/m}) = 33{,}6\,\text{dB}(\mu\text{V/m}) \end{aligned}$$

EXAMPLE 2 In the case of the amateur radio service in the 20-m-band, with a sensitivity of -11 dB(μV/m) and its protection ratio of 10 dB, taking into account the probability factors and their distributions (C.3.3.2 to C.3.3.4) a maximum permissible field strength of 29,4 dB(μV/m) can be calculated.

$$E_{\text{Limit}} = E_{\text{W}} - R_{\text{P}} - 10 \cdot \log_{10}\left(\frac{b_{\text{victim}}}{b_{\text{measurement}}}\right) + \mu_{\text{P4}} + \mu_{\text{P7}} + \mu_{\text{P8}} + t_{\alpha} \cdot \sqrt{\sigma_{\text{P4}}^2 + \sigma_{\text{P7}}^2 + \sigma_{\text{P8}}^2}$$

$$= \left(-11 - 10 - 10 \cdot \log_{10}\left(\frac{2700}{9000}\right) + 10 + 3{,}8 + 38 - 0{,}84 \cdot \sqrt{5^2 + 2^2 + 6^2}\right) \text{dB}(\mu\text{V/m}) = 29{,}4\,\text{dB}(\mu\text{V/m})$$

C.3.4 Global coupling factor $\overline{C}_{\text{PV}}$

C.3.4.1 Determination of coupling factors $C_{\text{PV}\,i\,\text{sim}}$ by simulation

C.3.4.1.1 General

Subclause C.3.4.1 gives the simulation results for the predefined groups of typical PV generators in the power range up to 20 kVA at a distance of 10 m from the outer boundary exclusively.

The following simulations (except for Group C) have been performed with the NEC2 calculating engine with a Sommerfeld ground model (conductivity σ = 5 mS/m and permittivity ε_r = 13). Due to this, direct connection to ground is not feasible and a certain capacitive coupling has been introduced using radial wires.

C.3.4.1.2 Simulation results for the coupling factor $C_{\text{PV}\,\text{Group A sim}}$ – Group A (Single-family detached houses)

For this simulation the average array height of the photovoltaic generator was assumed to be 6 m and with a tilt angle of 37°. In the model, the connection of the DC wires goes directly to the frame of the modules. Alternatively the whole PV panel structure can be simulated as a complete wire mesh forming a tilted rectangular plane with dimensions of 6 m × 4,5 m. The position of the PV power converter (GCPC) was assumed to be near the ground. See Figure C.7 and Figure C 8.

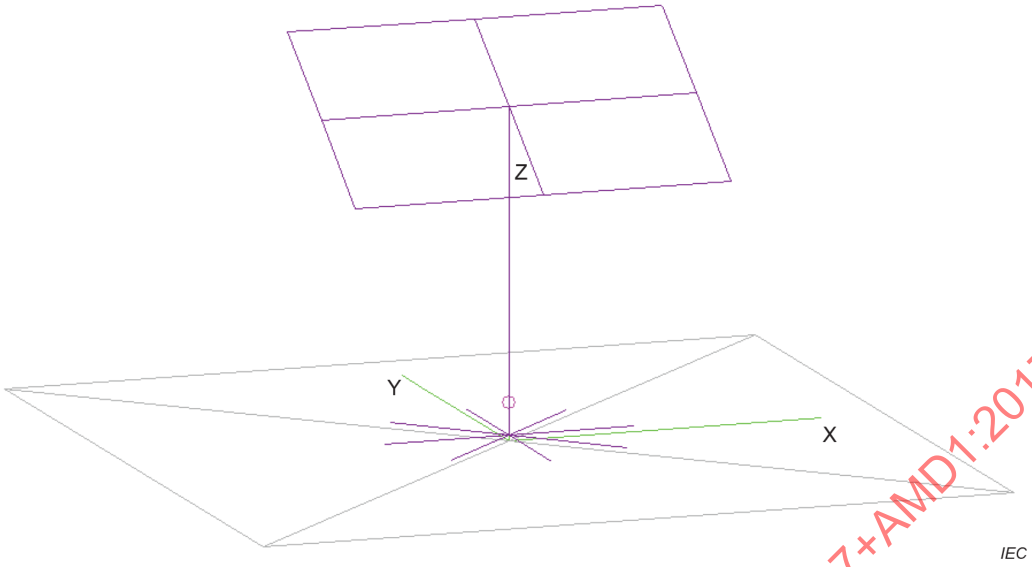


Figure C.7 – Geometrical representation of Group A PV generators

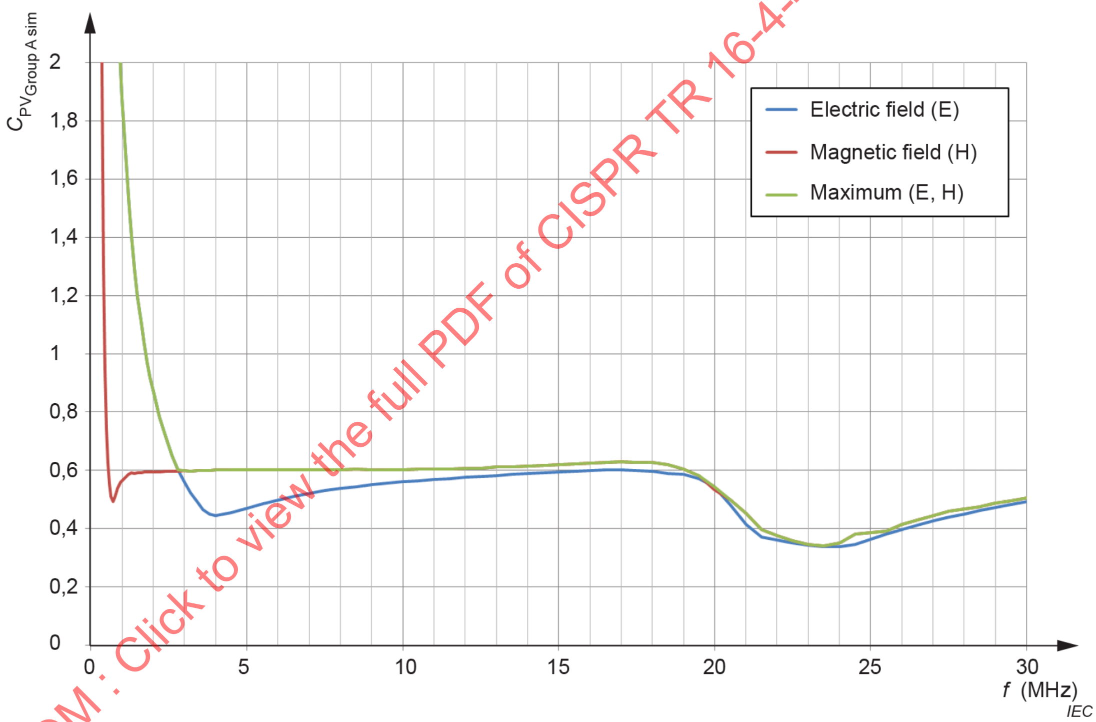


Figure C 8 – Combined coupling factor $C_{PV_{Group\,A\,sim}}$ for Group A PV generators (r = 10m)

C.3.4.1.3 Simulation results for the coupling factor $C_{PV_{Group\,B\,sim}}$ – Group B (Multi-storey house)

For this simulation the total resulting power of the photovoltaic system was assumed to be around 19 kVA, while the panels are practically installed on a flat top house of height 12 m. The house was simulated with four lightning protection wires down and connected to the ground at each corner. The position of the photovoltaic inverter is on the flat roof and driven against a conduction frame grounded by the lightning protection wires. See Figure C.9 and Figure C.10.

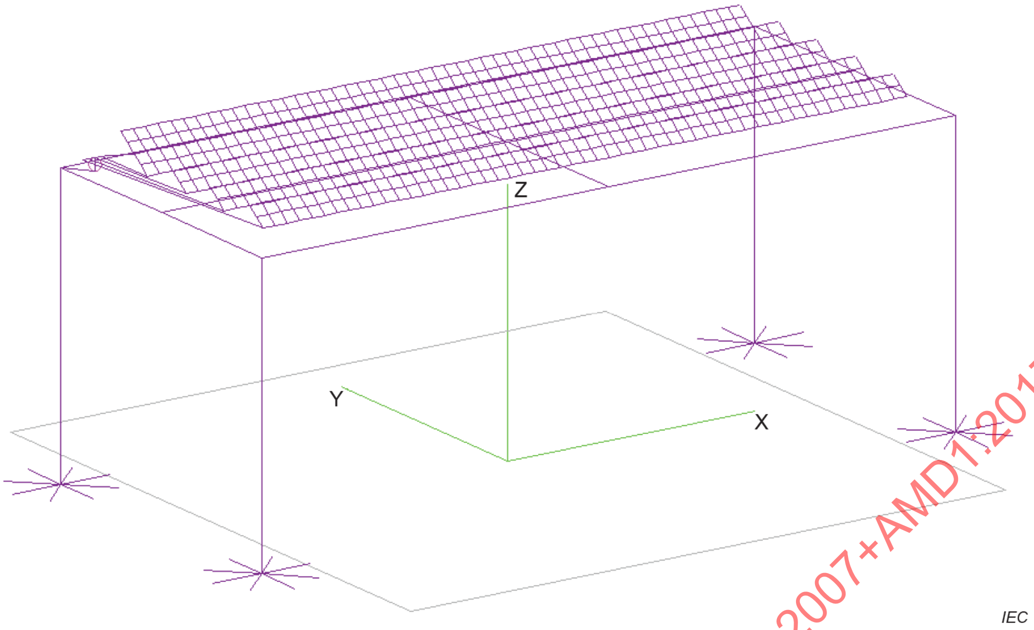


Figure C.9 – Geometrical representation of Group B PV generators

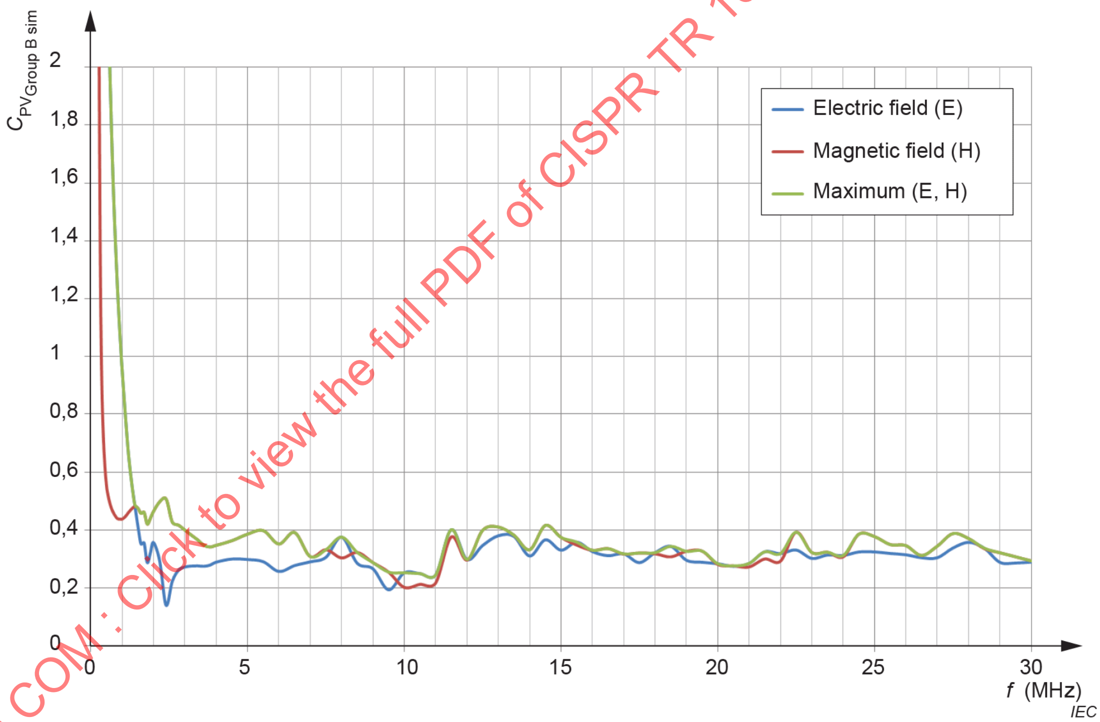


Figure C.10 – Combined coupling factor $C_{PV_{Group\ B\ sim}}$ for Group B PV generators (r = 10 m)

C.3.4.1.4 Simulation results for the coupling factor $C_{PV_{Group\ C\ sim}}$ – Group C (Sun tracker)

For this simulation the real installation of 7 × 4 modules and about 6 kVA was considered, while the maximum height above ground is 6,4 m and the width 7 m. The elevation angle of the PV panel plane is 30° and the centre of the plane is at a height of 5,75 m. The feed point is allocated at the bottom of the vertical DC power cable wiring. In this simulation, different Sommerfeld ground model parameters from those stated in C.3.4.1.1 were used. The values were derived in real measurements leading to average values of conductivity σ = 20 mS/m and permittivity ε_r = 27. See Figure C.11 and Figure C.12.

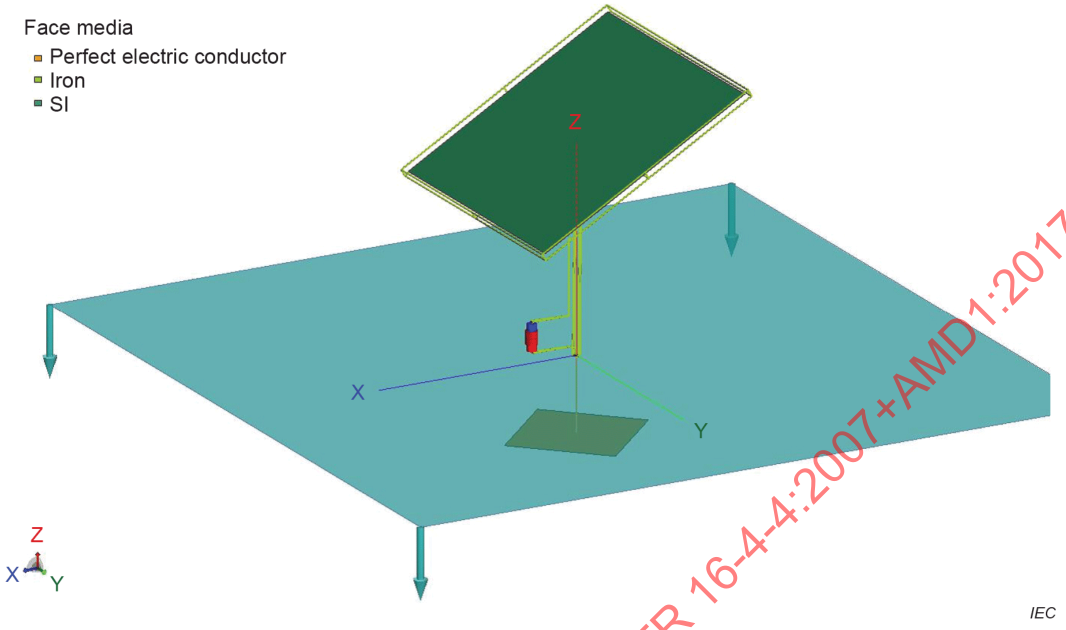


Figure C.11 – Geometrical representation of Group C PV generators

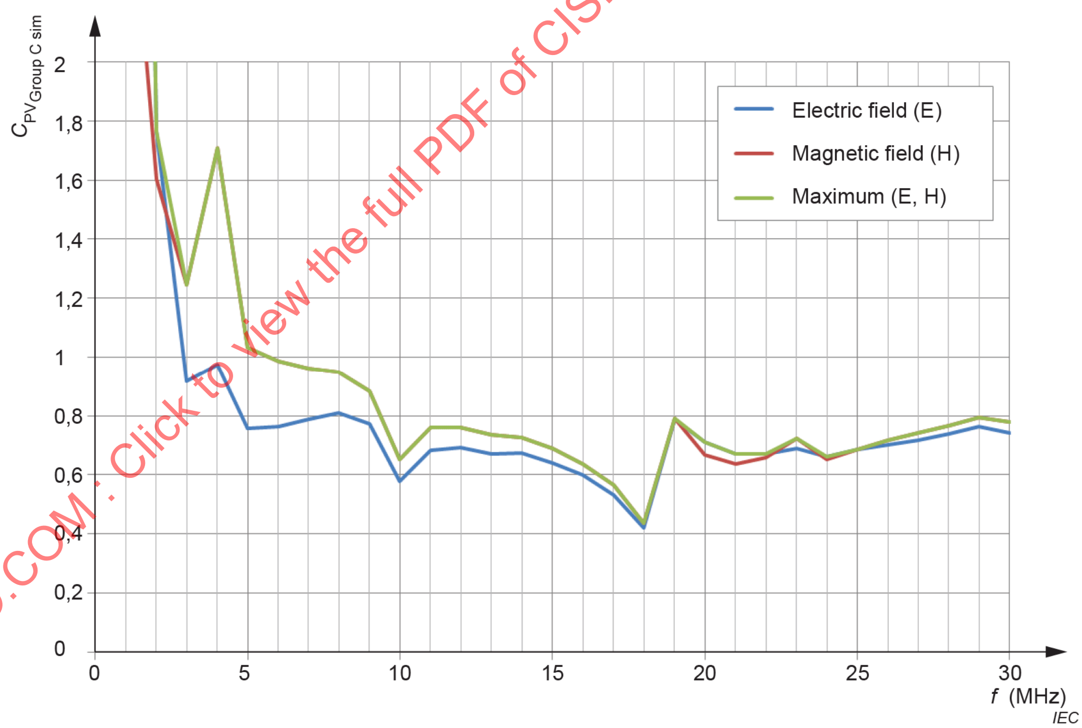


Figure C.12 – Combined coupling factor $C_{PV_{Group\ C\ sim}}$ for Group C PV generators (*r* = 10 m)

C.3.4.1.5 Simulation results for the coupling factor $C_{\text{PV}_{\text{Group D sim}}}$ – Group D (Large barns)

For this simulation the total resulting power was around 12 kVA; the maximum height is not larger than 6 m. See Figure C.13 and Figure C.14.

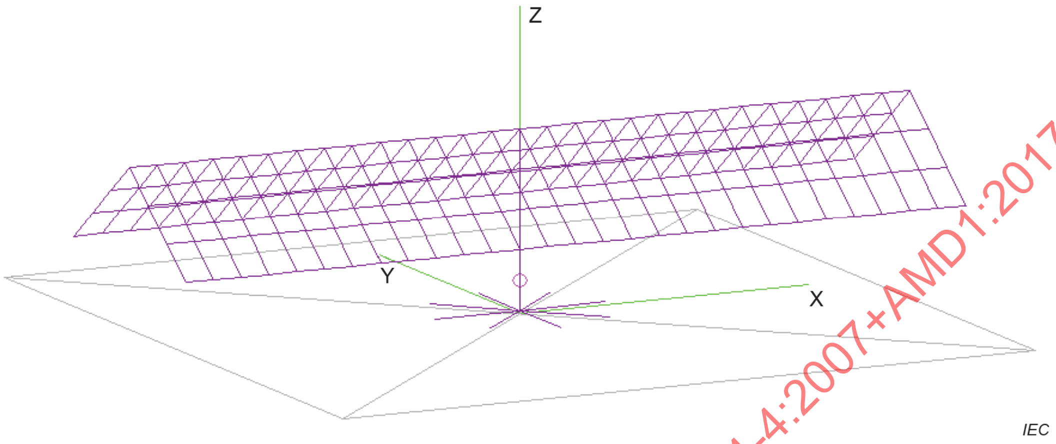


Figure C.13 – Geometrical representation of Group D PV generators

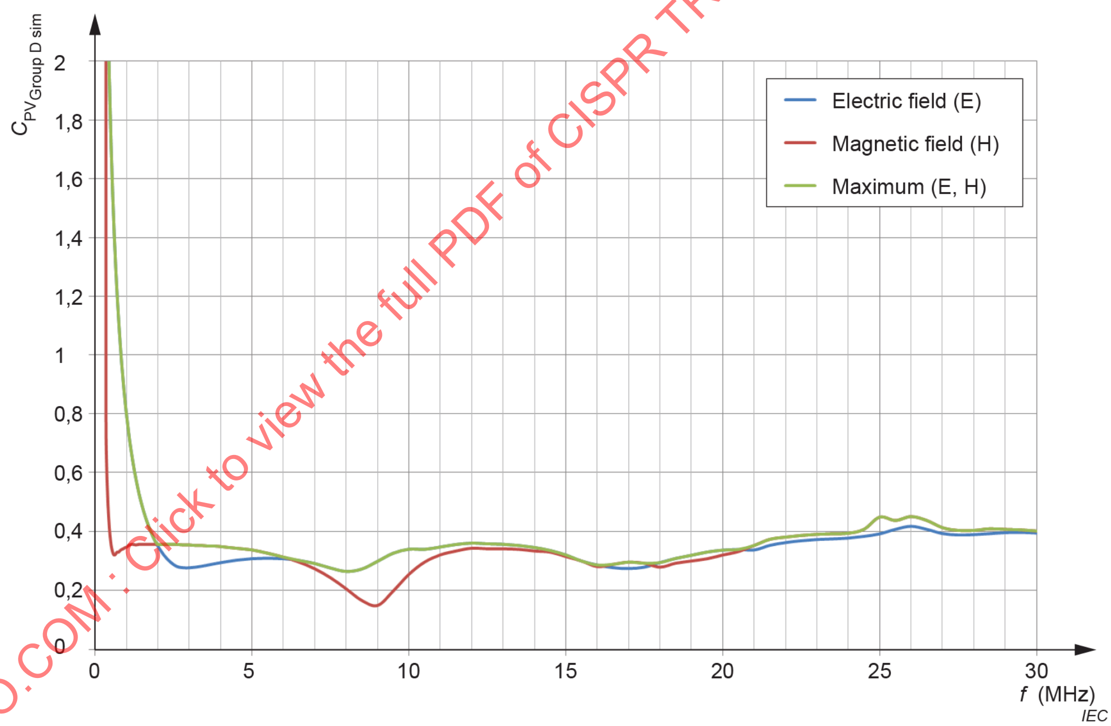


Figure C.14 – Combined coupling factor $C_{\text{PV}_{\text{Group D sim}}}$ for Group D PV generators (r = 10 m)

C.3.4.1.6 Coupling factor $C_{\text{PV}_{i\,\text{sim}}}$ at low frequencies

For all four models (Group A to D) the simulation results for the determination of a coupling factor $C_{i\text{sim}}$ between inserted power and resulting field strength at 10 m distance showed a roughly constant variation with frequency in the range from 4 MHz to 30 MHz. However, also in all simulations a distinct increase up to very large values in the low frequency range (< 4 MHz) was observed.

Detailed investigations have shown this effect to be the result of specific software assigned feed point properties assuming ideal, non-realistic electronic components gaining increasing significance in the low frequency range for small objects compared to the wavelength when power matched. A correction routine considering losses in the power matching network assumed by the simulating engine was introduced that provides an effective solution for a refined calculation in the critical frequency range from 150 kHz to 5 MHz.

C.3.4.1.7 Overview of $C_{\mathrm{PV}_{i\,\mathrm{sim}}}$ for the different groups of PV generators

With the artificial effect of a high increase of the coupling factor at low frequencies being compensated by the introduced correction routine (C.3.4.1.6), the coupling factor for each group can be represented by one non-frequency dependent average value (see Table C.1).

Table C.1 – Coupling factors $C_{\mathrm{PV}_{i\,\mathrm{sim}}}$

PV generator group	$C_{\mathrm{PV}_{i\,\mathrm{sim}}}$
Group A	0,50
Group B	0,35
Group C	0,79
Group D	0,35

C.3.4.2 Determination of coupling factors $C_{\mathrm{PV}_{i\,\mathrm{meas}}}$ by measurement

C.3.4.2.1 General

Although for the reasons described in C.2.4.3 this task is rather complex, measurements on three real installations could be carried out. In the subsequent evaluation process the objects were assigned to each represent one of the Groups A, C and D.

C.3.4.2.2 Description of the measurement setup

Figure C.15 shows a schematic representation of the measurement setup.

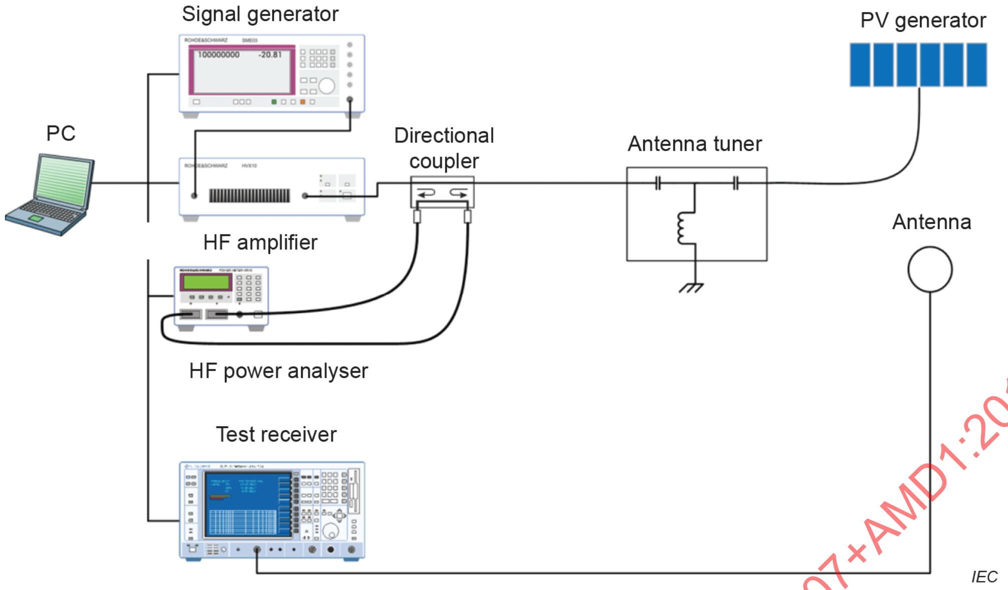


Figure C.15 – Measurement setup

A radio frequency signal was produced by a computer controlled signal generator and amplified to about 40 W. The signal then passed through a bidirectional coupler to monitor the forward and reflected power to ensure that most of the power is actually radiated. The antenna tuner helped to match the photovoltaic generator to an impedance of 50 Ω. When the antenna was properly tuned the reflected power was 20 dB less than the forward power. The fed power is the difference of the forward and reflected power. Then the electric and magnetic field strengths in 10 m distance from the photovoltaic generator were measured in three orientations (see Figure C.16).

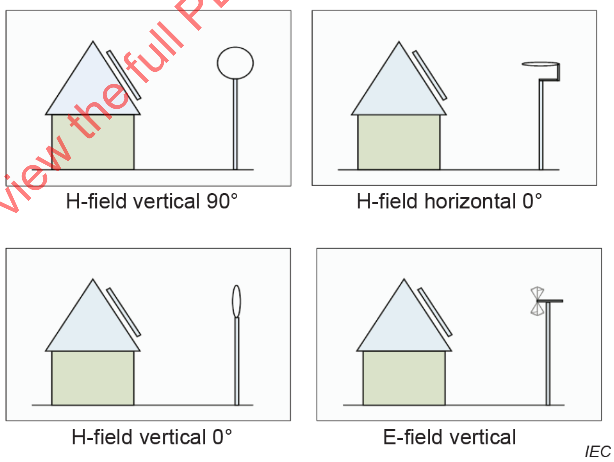


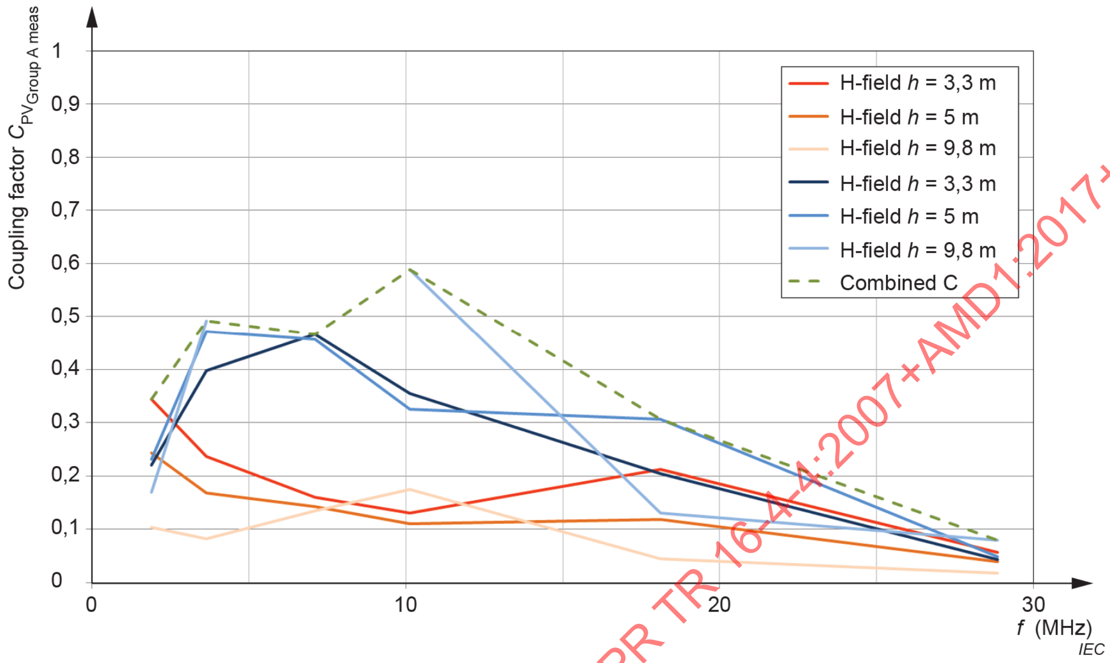
Figure C.16 – Antenna orientations

The combination of these three measurements by geometric addition delivered the final total field strength, which was then divided by the square root of the fed power. For practical reasons, data was recorded in the defined antenna positions at three different heights (h = 3,3 m, h = 5 m and h = 9,8 m).

Subclauses C.3.4.2.3 to C.3.4.2.5 give the measurement results for the three different sites including the combination procedure described in C.2.4.2. For the calculation of the final coupling factor, the data was averaged over frequency, using the data between 10 MHz and 30 MHz, where the typical non frequency dependent behaviour of the coupling factor is recognized.

C.3.4.2.3 Measurement results for the coupling factor $C_{PV\ Group\ A\ meas}$ – Group A (Single-family detached houses)

See Figure C.17.



NOTE Due to a measurement error the data point E-field h = 9,8 m at 7,1 MHz is missing.

Figure C.17 – Coupling factor $C_{PV\ Group\ A\ meas}$ for Group A PV generators

C.3.4.2.4 Measurement results for the coupling factor $C_{PV\ Group\ C\ meas}$ – Group C (Sun tracker)

See Figure C.18.

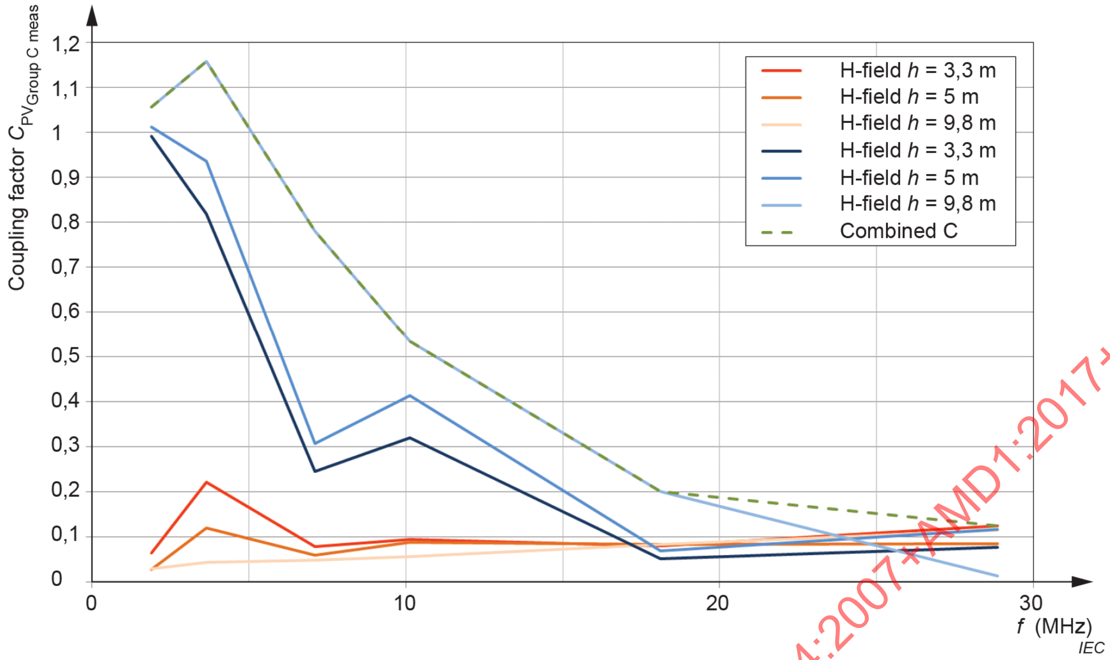


Figure C.18 – Coupling factor $C_{PV_{Group\ C\ meas}}$ for Group C PV generators

C.3.4.2.5 Measurement results for the coupling factor $C_{PV_{Group\ D\ meas}}$ – Group D (Large barn)

See Figure C.19.

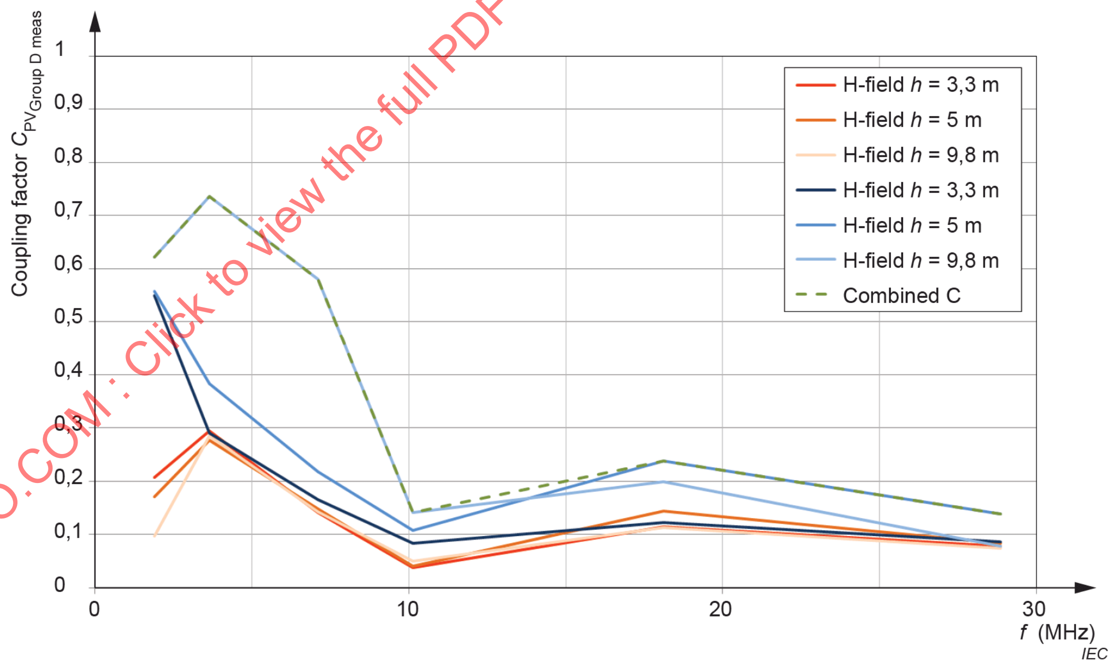


Figure C.19 – Coupling factor $C_{PV_{Group\ D\ meas}}$ for Group D PV generators

C.3.4.2.6 Overview of $C_{\mathrm{PV}_{i\,\mathrm{meas}}}$ for the different groups of PV generators

Table C.2 – Coupling factors $C_{\mathrm{PV}_{i\,\mathrm{meas}}}$ and calibration factors

PV generator group	$C_{\mathrm{PV}_{i\,\mathrm{meas}}}$	$cal_{\mathrm{PV}_{i\,\mathrm{meas}}}$
Group A	0,32	0,65
Group B	-	-
Group C	0,29	0,36
Group D	0,17	0,49

The calibration factor for each individual group was calculated by division of the measured and simulated coupling factor. As overall calibration factor the average of those individual calibration factors was taken resulting in a value of 0,5. This factor was used to correct for losses of a solar generator in a real environment with respect to the simulation results. See Table C.2.

C.3.4.2.7 Consolidated coupling factors (C_{PV_i})

Coupling factors were determined by simulation ($C_{\mathrm{PV}_{i\,\mathrm{sim}}}$) and measurement ($C_{\mathrm{PV}_{i\,\mathrm{meas}}}$). Table C.3 summarizes the results.

Table C.3 – Overview coupling factors C_{PV_i}

PV generator group	$C_{\mathrm{PV}_{i\,\mathrm{sim}}}$	$C_{\mathrm{PV}_{i\,\mathrm{meas}}}$	C_{PV_i}
Group A	0,50	0,32	0,25
Group B	0,35	-	0,18
Group C	0,79	0,29	0,36
Group D	0,35	0,17	0,18

Generally it has to be stated that, in context with the rather complex basic model, measurement as well as simulation is subject to various influence factors that cannot be covered completely. However, the findings of both evaluations being in the same order of magnitude indicates good correlation of the methods in this present case. The method of averaging was chosen to represent, as near as possible, the smallest deviation between both – measurement and simulation – while keeping the worst case approach. Additionally, a calibration of the simulated figures was done by multiplying the overall calibration factor with the individual simulation results to achieve a combination of both methods.

C.3.4.3 Determination of the global coupling factor $\overline{C}_{\mathrm{PV}}$

C.3.4.3.1 General

As the limits for the LV DC power port of power converters have not been determined taking into account different groups of PV systems, for the verification of the limits a group-independent mean value for the coupling factor and its variance is required.

In Subclause C.3.4.3, statistical data on the population density of PV generators in the field is used to draw conclusions on such a global coupling factor.

C.3.4.3.2 Determination of the distribution factors ρ_i from statistical data of PV generators in the field

In C.2.3.3 characteristic groups of PV generators were defined.

To be able to fill the model with suitable values of ρ_i, i.e. describing the probability of an individual PV generator of being in group *i*, statistical data on the distribution of PV generator types (group and ideally type of GCPC) in the field is needed.

Representative data on these parameters on a worldwide basis is difficult to obtain.

However data on the installed nominal power of PV systems in various countries is rather easy to acquire, as the operator of a PV generator site is obligated to register to be entitled to claim for remuneration for feeding into the public network.

Figure C.20 shows the ratio of registered PV power generating systems in Germany.

NOTE 1 Data from the German Federal Network Agency (2009 to February 2015 (1 038 697 entries)). The database does only include grid-connected installations. The database does not consider changes (deactivation of sites, subsequent corrections, etc.).

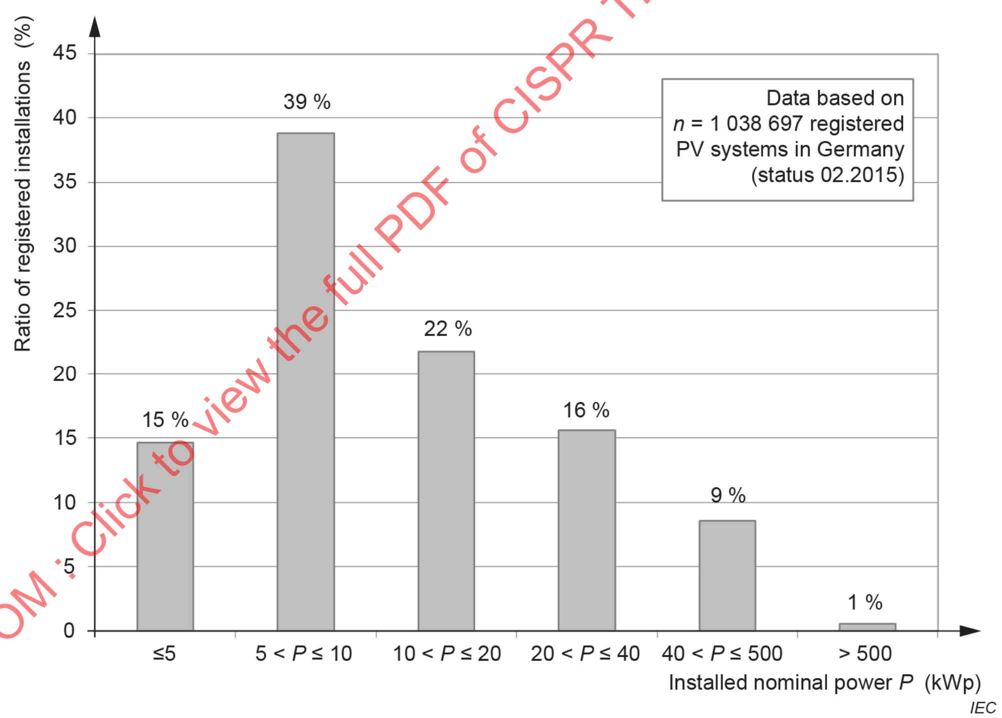


Figure C.20 – Ratio of registered PV power generating systems in Germany

Figure C.21 shows the ratio of registered PV power generating systems in Sweden.

NOTE 2 Data from the Swedish Energy Agency (2009 to 2016 (3 813 entries)). The database does only include grid-connected installations. The database does not consider changes (deactivation of sites, subsequent corrections, etc.).

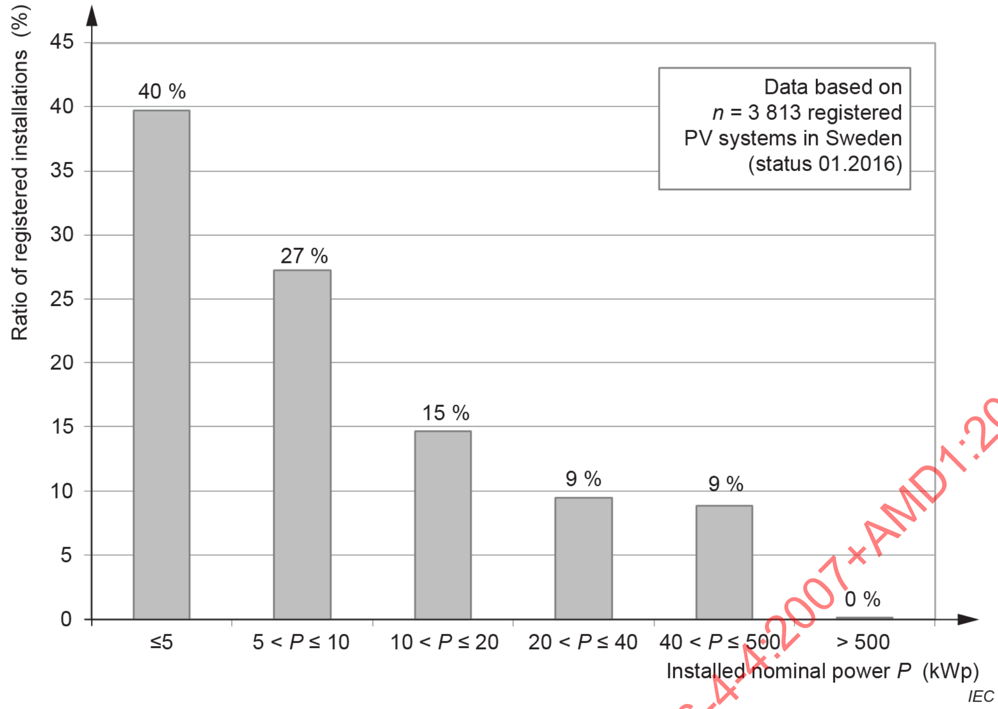


Figure C.21 – Ratio of registered PV power generating systems in Sweden

The PV systems with a nominal installed power of up to 20 kWp representing the major part of all systems with a ratio of 76 % (Germany) and 82 % (Sweden), can be supposed to be mainly applications assignable to Group A and Group B.

To obtain suitable values of ρ_i, the following estimation was performed on how the predefined groups are presumably represented in the installed nominal power ranges and subsequent weighting with respect to the particular power range (see Table C.4).

Table C.4 – Estimation of ρ_i

		Installed nominal power *P* [kWp]			Estimated ρ_i
		≤ 5	5 < *P* ≤ 10	10 < *P* ≤ 20	
	Part of the entirety of PV systems with installed nominal power *P* ≤ 20 kWp ***(from statistical data)***	0,19	0,52	0,29	
Estimated part of PV systems in the respective range of installed nominal power	**Group A – Single-family detached houses**	0,9	0,45	0,15	0,5
	Group B – Multi-storey buildings with flat roof tops	0	0,45	0,5	0,316 7
	Group C – Sun tracking supports (“trees”)	0,1	0,05	0	0,05
	Group D – Large barns in the countryside	0	0,05	0,35	0,133

NOTE 3 All values are given as dimensionless quantities; respective entirety of all parts is represented by value 1.

These values will be used in the following for the determination of the global coupling factor $\overline{C}_{\text{PV}}$ (see C.3.4.3.3).

C.3.4.3.3 Estimation for a global coupling factor $\overline{C}_{PV}$

Application of Equation (C.4) using the coupling factors spelled out in C.3.4.2.7 and the distribution factors ρ_i determined in C.3.4.3.2 will result in an estimation for a global coupling factor $\overline{C}_{PV}$ (Equation (C.26)).

$$\overline{C}_{PV} = \sum_{\text{all groups}} C_{PVi} \times \rho_i = 0{,}22 \frac{\sqrt{\Omega}}{\text{m}} \tag{C.26}$$

C.3.5 Determination of the maximum permissible disturbance power P_L injected into the PV generator

According to Equation (C.7) the maximum permissible disturbance power P_L can be derived by combining the function E_{Limit} with the global coupling factor $\overline{C}_{PV}$ for each frequency.

EXAMPLE For the example of the shortwave radio broadcast service in the 31-m-band introduced in C.3.2, the permissible power can be calculated. Using 33,6 dBµV/m as permissible field strength, which converts to 47,9 µV/m the following is obtained:

$$P_L = \frac{E_{\text{Limit}}^2}{\overline{C}_{PV}^2} = \frac{\left(47{,}9 \frac{\mu\text{V}}{\text{m}}\right)^2}{\left(0{,}22 \frac{\sqrt{\Omega}}{\text{m}}\right)^2} = -43{,}2\,\text{dBm} = 0{,}047\,\mu\text{W} \tag{C.27}$$

C.3.6 Consideration of mismatch conditions for the verification of the limits

The available data base for relevant factors of the mismatch conditions (m_{TC} and m_L introduced in C.2.5) being rather weak, the following options for consideration in the verification process were noted:

a) ignore assumptions for realistic mismatch conditions and calculate the worst case (i.e. maximum power matching in the test case and at the site of the installed PV generator);

b) determine typical mismatch losses by (impedance) measurements on PV generator installations and GCPCs;

c) use simulation tools such as the Monte Carlo method and operate with reasonable variation ranges for the complex load and source impedances of the PV generators and GCPCs.

During the measurements of the coupling factor $C_{PV_{i\,\text{meas}}}$ (C.3.4.2), the complex output impedance of the GCPC (Z_S) and of the PV generator (Z_L) were measured. On the three different sites (real objects) the impedance values were taken at 100 different frequency points altogether covering the interval from 150 kHz to 30 MHz. The sites represent the Groups A, C and D and were used to calculate the mismatch losses over frequency using the equations given in C.2.5.2 and C.2.5.3. As expected, the mismatch loss factors vary depending on the individual frequency. However, as this consideration is based on a statistical process, averaging of those loss factors over frequency is feasible.

For the simulation some assumptions have to be made prior to calculation. In the test case the load impedance Z_{TC} is fixed at 150 Ω, while the source impedance Z_S is unknown. Theoretically any source impedance would be possible, but realistically part of the complex plane is likely to cover typical cases. From the measurement results it can be concluded, that no source impedance has been outside the interval for the real part between 1 Ω and 1 000 Ω and for the imaginary part −1 000 j Ω and 1 000 j Ω. Therefore this interval was chosen for the statistical determination of m_L.

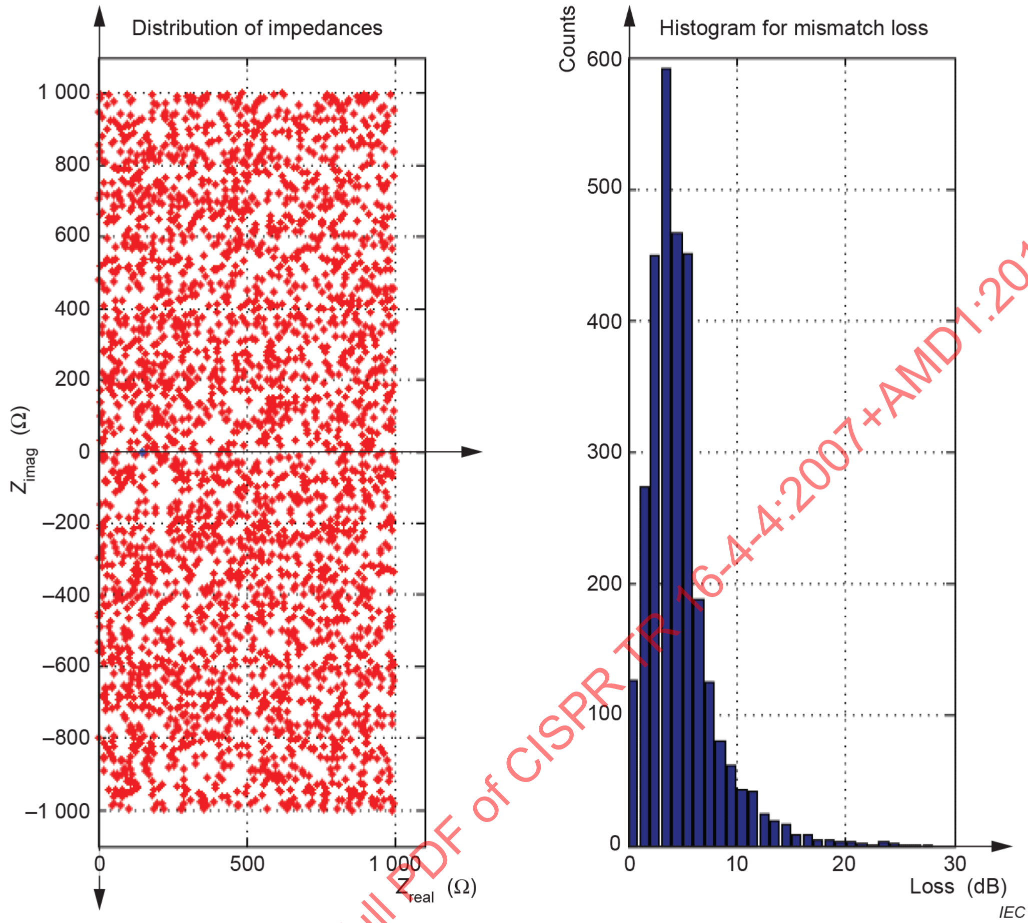


Figure C.22 – Simulation results m_{TC} (test case)

The left diagram in Figure C.22 shows the randomly distributed load impedances (red) in part of the complex plane, while the load impedance in the test case is fixed (blue dot at 150 Ω). The right diagram in Figure C.22 shows the number of impedance pairs resulting in a dB-bin.

Also for the use case an assumption is needed for the load impedance Z_L presented by the PV generator: Guidance was given by the measurement results, which exclusively show values in an interval of 5 Ω to 500 Ω for the real part and −1 000 j Ω and 1 000 j Ω for the imaginary part.

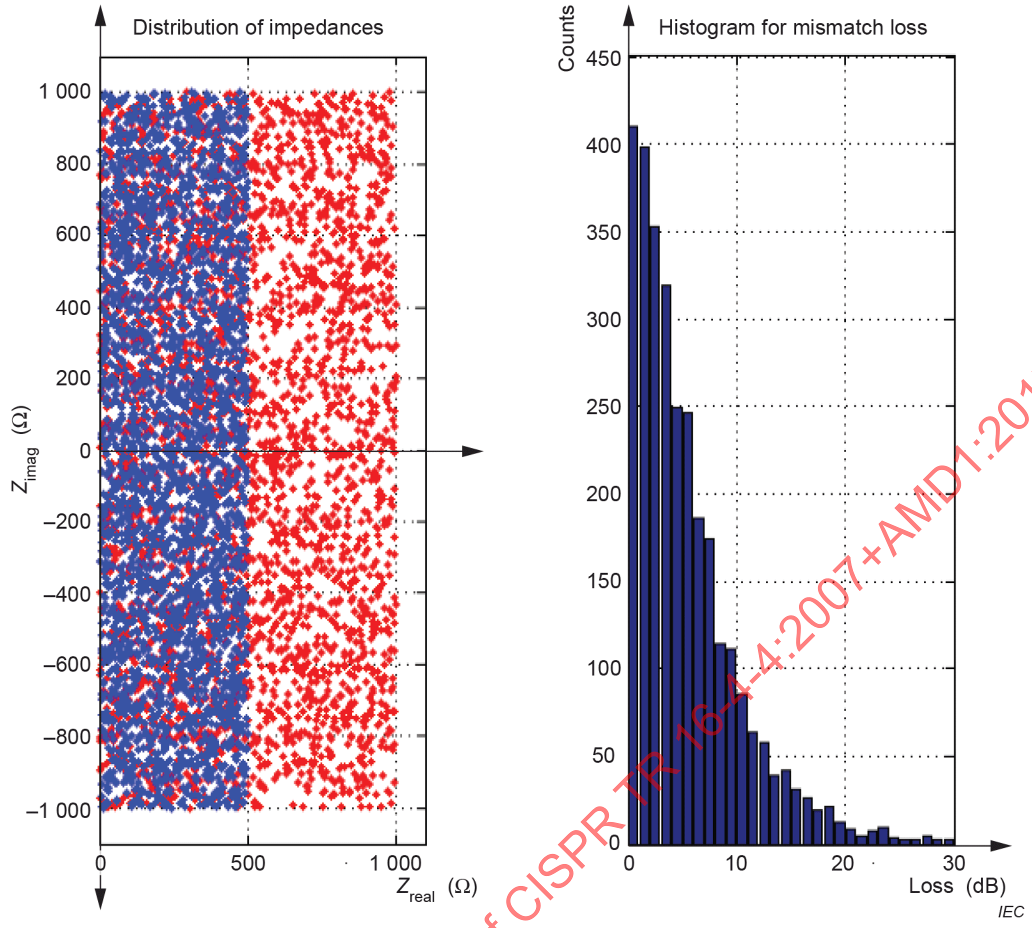


Figure C.23 – Simulation results m_L (use case)

The left diagram in Figure C.23 shows the randomly distributed source (blue) and load (red) impedances in part of the complex plane. The right diagram in Figure C.23 shows the number of impedance pairs resulting in a dB-bin. Most random pairs result in a rather low loss value.

Table C.5 gives an overview on the results determined from measurement and simulation and the combined average values of both approaches.

Table C.5 – Mismatch loss values m_L and m_{TC} determined by measurement and simulation

		m_{TC}	m_L
Measurement	Group A	0,74	0,45
	Group C	0,58	0,58
	Group D	0,20	0,06
	Average of all groups	**0,51**	**0,36**
Simulation	Monte Carlo	**0,40**	**0,43**
Combined	Average	**0,455**	**0,395**
	Average [dB]	3,42	4,03

The calculation results in the combined average mismatch factor of m_{TC} = 0,40 for the test case and of m_L = 0,43 for the use case. Both values are very close together and of the same order of magnitude as the averaged measurement result.

For the task of limit verification the combined average values of simulation and measurement are used (m_{TC} = 3,42 dB and m_{L} = 4,03 dB). However, it can be stated, that the approach of ignoring the mismatch situation would not be connected with great impact on the result as the determined corrections in this evaluation are rather small (below 1 dB).

C.3.7 Calculation of $U_{TC\ Limit}$ for radio services and applications in the frequency range from 150 kHz to 30 MHz

In a last step, from the calculated maximum permissible power in the test case $P_{TC\ limit}$ the disturbance voltage limit for type tests on GCPCs at test sites $U_{TC\ Limit}$ was derived using Equation (C.17).

Table C.6 gives an overview of the most important parameters (determined according to the procedure described in C.3.1 to C.3.6) for well-established radio services in the frequency range from 150 kHz to 30 MHz.

For each radio service a representative $U_{TC\ limit}$ ($f_{radio\ service}$) value was calculated based on its specific model input parameters (see Figure C.24).

Table C.6 – Calculation of $U_{TC\ Limit}$ for radio services between 150 kHz and 30 MHz at a distance of d = 10 m

Frequency [MHz]	E_w [dBµV/m]	R_P [dB]	Service	E_{ir} [dBµV/m]	μ_{P7} Time [dB]	σ_{P7} Time [dB]	μ_{P8} Location [dB]	σ_{P8} Location [dB]	μ_{P4} Frequency [dB]	σ_{P4} Frequency [dB]	E_{Limit} [dBµV/m]	$\overline{C}_{PV}$ Global coupling factor [Ω/m]	P_L [dBm]	$P_{TC\ Limit}$ [dBm]	$U_{TC\ Limit}$ [dBµV]
0,20	72	30	LF	42,0	3,8	2	8	3	10	5	58,6	0,22	-18,2	-17,6	94,1
0,28	71	30	LF	41,0	3,8	2	8	3	10	5	57,6	0,22	-19,2	-18,6	93,1
0,48	-1	10	AmaR	-5,8	3,8	2	38	6	10	5	39,4	0,22	-37,5	-36,9	74,9
1,00	60	30	MF	30,0	3,8	2	8	3	10	5	46,6	0,22	-30,2	-29,6	82,1
1,91	-3	10	AmaR	-7,8	3,8	2	38	6	10	5	37,4	0,22	-39,5	-38,9	72,9
3,75	-6	10	AmaR	-10,8	3,8	2	38	6	10	5	34,4	0,22	-42,5	-41,9	69,9
3,95	47	27	HF	20,0	3,8	2	8	3	10	5	36,6	0,22	-40,2	-39,6	72,1
5,95	45	27	HF	18,0	3,8	2	8	3	10	5	34,6	0,22	-42,2	-41,6	70,1
6,10	45	27	HF	18,0	3,8	2	8	3	10	5	34,6	0,22	-42,2	-41,6	70,1
7,15	-8	10	AmaR	-12,8	3,8	2	38	6	10	5	32,4	0,22	-44,5	-43,9	67,9
7,25	45	27	HF	18,0	3,8	2	8	3	10	5	34,6	0,22	-42,2	-41,6	70,1
7,33	45	27	HF	18,0	3,8	2	8	3	10	5	34,6	0,22	-42,2	-41,6	70,1
9,45	44	27	HF	17,0	3,8	2	8	3	10	5	33,6	0,22	-43,2	-42,6	69,1
9,70	44	27	HF	17,0	3,8	2	8	3	10	5	33,6	0,22	-43,2	-42,6	69,1
10,13	-10	10	AmaR	-14,8	3,8	2	38	6	10	5	30,4	0,22	-46,5	-45,9	65,9
11,63	43	27	HF	16,0	3,8	2	8	3	10	5	32,6	0,22	-44,2	-43,6	68,1
11,80	43	27	HF	16,0	3,8	2	8	3	10	5	32,6	0,22	-44,2	-43,6	68,1
12,05	43	27	HF	16,0	3,8	2	8	3	10	5	32,6	0,22	-44,2	-43,6	68,1
13,60	43	27	HF	16,0	3,8	2	8	3	10	5	32,6	0,22	-44,2	-43,6	68,1
13,70	43	27	HF	16,0	3,8	2	8	3	10	5	32,6	0,22	-44,2	-43,6	68,1
13,87	43	27	HF	16,0	3,8	2	8	3	10	5	32,6	0,22	-44,2	-43,6	68,1
14,18	-11	10	AmaR	-15,8	3,8	2	38	6	10	5	29,4	0,22	-47,5	-46,9	64,9
15,35	42	27	HF	15,0	3,8	2	8	3	10	5	31,6	0,22	-45,2	-44,6	67,1
15,70	42	27	HF	15,0	3,8	2	8	3	10	5	31,6	0,22	-45,2	-44,6	67,1

Frequency [MHz]	E_w [dBµV/m]	R_P [dB]	Service	E_{ir} [dBµV/m]	μ_{P7} Time [dB]	σ_{P7} Time [dB]	μ_{P8} Location [dB]	σ_{P8} Location [dB]	μ_{P4} Frequency [dB]	σ_{P4} Frequency [dB]	E_{Limit} [dBµV/m]	$\overline{C}_{PV}$ Global coupling factor [Ω/m]	P_L [dBm]	$P_{TC\ Limit}$ [dBm]	$U_{TC\ Limit}$ [dBµV]
17,50	42	27	HF	15,0	3,8	2	8	3	10	5	31,6	0,22	-45,2	-44,6	67,1
17,80	42	27	HF	15,0	3,8	2	8	3	10	5	31,6	0,22	-45,2	-44,6	67,1
18,10	-12	10	AmaR	-16,8	3,8	2	38	6	10	5	28,4	0,22	-48,5	-47,9	63,9
18,95	41	27	HF	14,0	3,8	2	8	3	10	5	30,6	0,22	-46,2	-45,6	66,1
21,23	-13	10	AmaR	-17,8	3,8	2	38	6	10	5	27,4	0,22	-49,5	-48,9	62,9
21,65	41	27	HF	14,0	3,8	2	8	3	10	5	30,6	0,22	-46,2	-45,6	66,1
24,94	-14	10	AmaR	-18,8	3,8	2	38	6	10	5	26,4	0,22	-50,5	-49,9	61,9
26,00	40	27	HF	13,0	3,8	2	8	3	10	5	29,6	0,22	-47,2	-46,6	65,1
28,80	-16	10	AmaR	-20,8	3,8	2	38	6	10	5	24,4	0,22	-52,5	-51,9	59,9

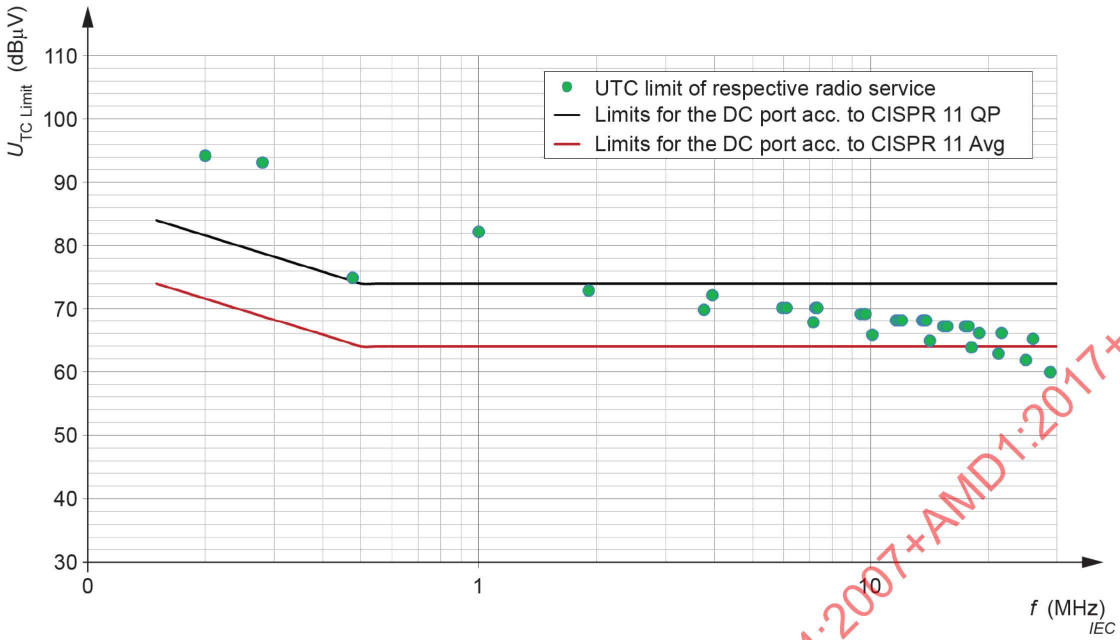


Figure C.24 – Overview of the calculated $U_{TC\ Limit}$ values for radio services between 150 kHz and 30 MHz at a distance of d = 10 m

The analysis of the green dots in Figure C.24, each representing a radio service from the radio service database, implies to average the values over frequency in order to obtain a horizontal limit line as existing in CISPR 11. Omitting the values of the first three radio services as the limit is sloping in this frequency range a value of $\overline{U}_{\text{TC Limit}}\left(f_{\text{radio services}}\right) = 67{,}9\ \text{dBµV}$ is obtained for the average detector.

Although the application of the introduced model was based on various input parameters and contains many statistical processes, it leads to a calculated limit value comparable to the established limit in CISPR 11.

Annex D
(informative)

Model for the estimation of radiation from in-house extra low voltage (ELV) lighting installations

D.1 Overview

D.1.1 Content and scope

This annex presents the method used to verify the limits set for extra-low voltage (ELV) lamps at their terminal connector which were introduced in CISPR 15:2013/AMD1:2015[5] [14] and included in the subsequent edition of CISPR 15 published in 2018. This annex presents a model for estimation of the radiated disturbance from (ELV) lighting installations that are typically applied in residential environments. The modelling is limited to the radio frequency range from 9 kHz to 30 MHz.

The model is based on theoretical assumptions. Numerical simulation is used for exercizing the models.

The model is limited to disturbances arising from a single unit of an ELV lamp. Aggregation effects of multiple ELV lamps in an installation are not addressed. This annex does not consider the effects of disturbances from ELV power sources that are used to supply ELV lamps

D.1.2 Application configurations of ELV lamps

ELV lamps are usually small-sized lamps (MR 16 type) that are connected via a two-wire ELV cable to a power source. The power source is usually an electronic or magnetic transformer that is fed via the low-voltage AC mains network. Typical applications are shown in Figure D.1.

Normally, one or more of these ELV lamps are applied in a luminaire in which each lamp is connected via a two-wire cable to the power source. The two individual leads of the ELV cable run closely together inside the luminaire (Figure D.1a)). Sometimes, ELV lamps are connected in an arbitrary distributed way to a flexible rail installation below a ceiling or on a wall as shown in Figure D.1b). The two wires or metal bars of the rail system provide the ELV connection from each lamp to the power source.

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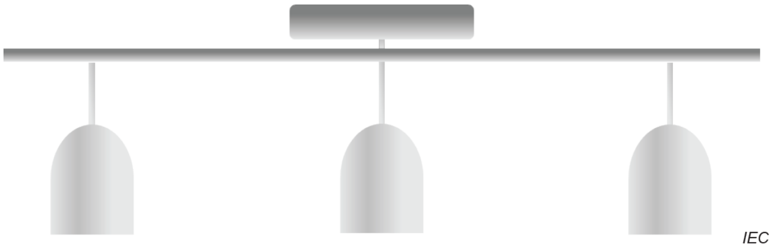
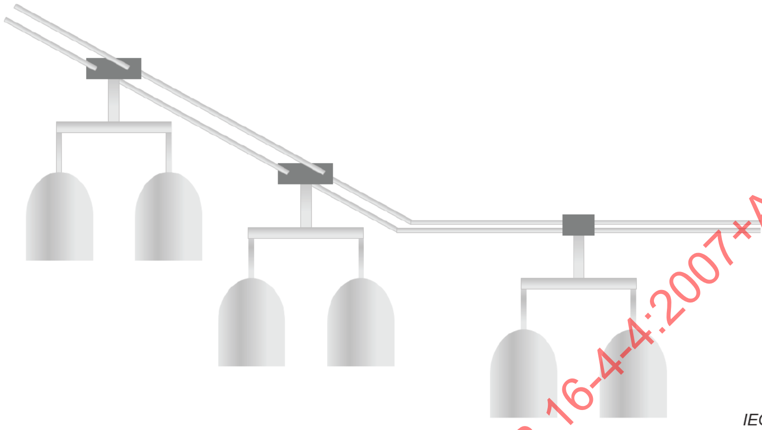


a) ELV lamps applied in a luminaire



b) ELV lamps applied in a flexible rail installation

Figure D.1 – Application of ELV lamps

D.1.3 Potential interference from ELV lamps

Previous types of ELV lamps were passive tungsten halogen lamps which were fed via an AC magnetic transformer. A typical circuit is shown in Figure D.2. In the past there was no risk for radio disturbance from these passive halogen ELV lamps and the 50 Hz or 60 Hz magnetic transformers. In the past decade the magnetic transformers have been replaced by small-sized electronic transformers. Furthermore, ELV halogen lamps have been replaced by active LED-lamps. As a result, electronic (LED) ELV-lamps could potentially cause radio disturbances via the ELV wiring it is connected to. Therefore, since the publication of CISPR 15:2013/AMD1:2015 [14], specific limits have been introduced for the ELV terminals of ELV lamps.

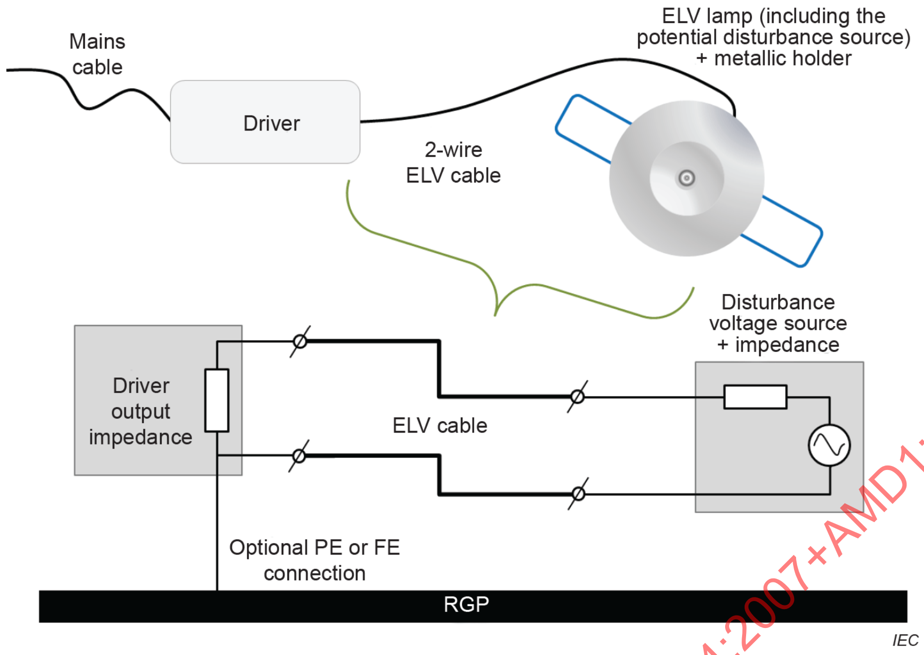


Figure D.2 – Typical components and wiring for an ELV lamp connected to a power source and the associated lumped-circuit model of the ELV part

D.1.4 Interference scenarios and associated CISPR 15 limits for ELV equipment

Figure D.3 shows the potential interference scenarios of an ELV lamp connected via an auxiliary power source to the AC mains network.

It is assumed that the lamp contains a differential-mode disturbance source with an unknown impedance.

ELV lamps are usually small and have symmetrical connections with an ELV network. It is assumed that the capacitance of the ELV lamp to the remote ground is so small, that no common mode disturbance current can be introduced via capacitive coupling of the ELV lamp.

The differential-mode disturbance current flows into a symmetric two-wire system, the two individual wires of which run parallel and have equal lengths. So, for a pure symmetrical installation, the disturbance current in each wire of the ELV cable has a phase difference of 180°. In normal luminaire applications (as depicted in Figure D.1a)) the length of the ELV wires is limited and the distance between the wires is very small.

In some, more rare applications (example as depicted in Figure D.1b)), ELV lamps are connected using a flexible rail wiring system, of which the two individual wires can have a longer length, and which may be separated by a couple of centimeters. If such a rail system runs close to a conductive structure in a ceiling or wall, an unbalance may be introduced giving rise to a common-mode current.

In such practical installations, branching of the ELV wiring and application of multiple ELV lamps distributed across the wiring installation is often applied. But this will not be considered in the modelling in this annex.

Figure D.3 shows the potential interference scenarios from both the ELV part and the mains part (= low voltage – LV part) of an ELV system.

CISPR 15:2018 provides two methods for measuring disturbances from ELV lamps. Where the ELV lamps are applied with a specific power source (restricted ELV lamps), then the disturbance level of this specific combination shall be measured at the mains side of this specific power source using an artificial mains network (AMN) and the normal mains disturbance voltage limits of Table 1 of CISPR 15:2018.

If there is no restriction for the application of power sources (non-restricted ELV lamps), then the limits for conducted disturbance voltages of Table 4 of CISPR 15:2018 apply using an AMN at the ELV interface (see Table D.1). These limits are 26 dB above the Table 1 limits of CISPR 15:2018 that apply for the mains voltage (LV) disturbances. The value of 26 dB is based on the typical value of the ELV power source insertion loss of the differential mode (DM) current.

Hence, the following potential interference scenarios can be recognized from Figure D.3:

a) conducted coupling from mains disturbance currents (LV-side) to neighbouring mains connected radio receivers;
b) radiated coupling from mains disturbance currents (LV-side) to neighbouring radio receivers;
c) radiated coupling from the common mode (CM) disturbance currents in the ELV cable to neighbouring radio receivers;
d) radiated coupling from the DM disturbance currents in the ELV cable to neighbouring radio receivers;

Coupling scenarios a) and b) are covered by the normal mains disturbance voltage limits of Table 1 of CISPR 15:2018.

Coupling scenarios c) and d) are covered by the limits for conducted disturbance voltages of Table 4 of CISPR 15:2018 (using an AMN at the ELV interface). In addition, coupling scenario d) is also covered by the magnetic field limits of Table 8 or Table 9 of CISPR 15:2018, which conditionally apply (see 5.3.4.1 of CISPR 15:2018).

D.1.5 Modelling of two interference scenarios

Radiated coupling from the DM disturbance currents, i.e. scenario d) of D.1.4, in the two-wire ELV cable to the electromagnetic environment is possible, as the current is not flowing exactly at the same location, but at a separation distance d from the wires. The largest separation distance will also generate the highest level of the disturbance field. The model of this DM interference scenario is described in more detail in Clause D.2.

A second coupling effect can occur if the symmetry of the wire system is compromised, i.e. by a coupling to remote ground, which may be larger for one of the wires and smaller for the other wire. This would result in some conversion of DM to CM current and the ELV wiring then acts as a common mode radiator. This is coupling scenario c) of D.1.4 and is described in more detail in Clause D.3.

For modelling of the two scenarios, the separation d will be limited to 10 cm, as practical installations are unlikely to show larger distances (see also D.4.3).

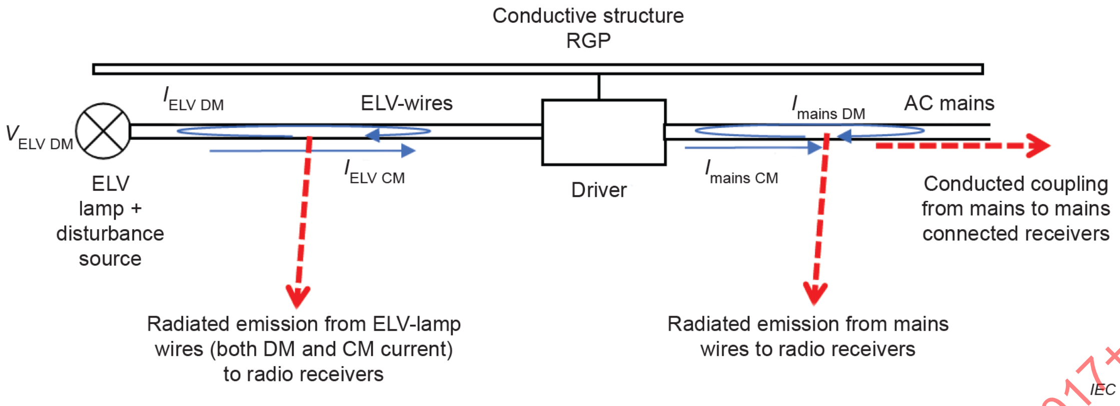


Figure D.3 – Coupling scenarios

D.2 Direct coupling of the differential mode current

Two wires with a separation distance *d* carry an equal current flowing in opposite direction as shown in Figure D.4.

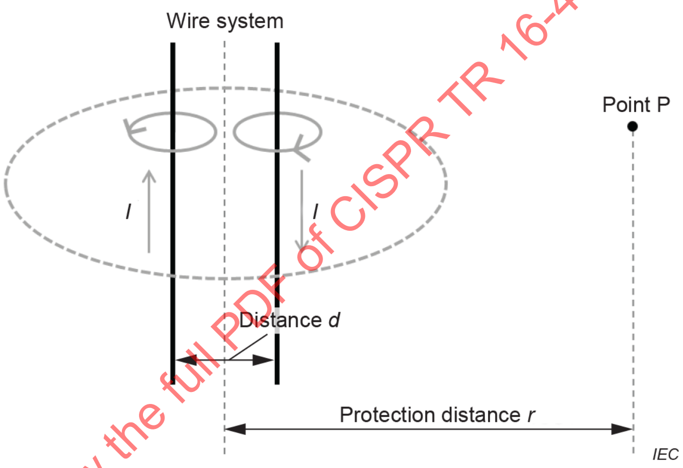


Figure D.4 – Two wire scenario

In point P, which is separated from the wire system by the protection distance *r*, both wires produce a magnetic field, which is described by the Biot-Savart-Law given in Equation (D.1).

$$H = \frac{I}{2\pi r} \tag{D.1}$$

If both wires are at the exact same distance from point P, the two magnetic field components will cancel each other out, as the current is flowing in opposite direction delivering a minus sign in the superposition of the two field components at point P. As one wire is a bit closer to point P and the other a bit further away, the cancellation is not perfect. Equation (D.2) shows the resulting field strength under the assumption that the distance between the wires is much smaller than the protection distance.

$$H = H_1 + H_2 = \frac{I}{2\pi\left(r - \frac{d}{2}\right)} + \frac{-I}{2\pi\left(r + \frac{d}{2}\right)} = \frac{I}{2\pi} \times \frac{d}{r^2 - \frac{d^2}{4}} \approx \frac{I}{\pi} \times \frac{d}{2r^2} \tag{D.2}$$

Defining the coupling factor for current to magnetic field (for the described effect due to the wire system) $C_{WS,I}$ leads to Equation (D.3) and inserting the protection distance of r = 10 m and the wire separation distance d = 0,1 m (see D.1.5) results in a fairly small value.

$$C_{WS,I} = \frac{H}{I} = \frac{1}{\pi} \times \frac{d}{2r^2} = \frac{1}{\pi} \times \frac{0{,}1\text{m}}{2 \times (10\text{m})^2} = 1{,}59 \times 10^{-4} \frac{1}{\text{m}} \tag{D.3}$$

Taking the voltage limit of 82 dBµV (150 kHz ≤ f ≤ 5 MHz) and 86 dBµV (5 MHz < f ≤ 30 MHz) specified in Table 4 of CISPR 15:2018 and considering a differential mode impedance of Z_{DM} = 100 Ω, this results in maximum magnetic field strength values according to Equation (D.4).

$$\begin{aligned}
&V_{\text{Limit }150\text{ kHz} \le f \le 5\text{ MHz}} = 82\text{ dB}\mu\text{V} = 0{,}0126\text{ V} \xrightarrow{100\,\Omega} 1{,}26 \times 10^{-4}\text{ A} \\
&V_{\text{Limit }5\text{ MHz} < f \le 30\text{ MHz}} = 86\text{ dB}\mu\text{V} = 0{,}02\text{ V} \xrightarrow{100\,\Omega} 2 \times 10^{-4}\text{ A} \\
&H_{\max 150\text{ kHz} \le f \le 5\text{ MHz}} = C_{WS,I} \times I = 1{,}59 \times 10^{-4} \frac{1}{\text{m}} \times 1{,}26 \times 10^{-4}\text{ A} = 2{,}00 \times 10^{-8} \frac{\text{A}}{\text{m}} = -34\text{ dB}\frac{\mu\text{A}}{\text{m}} \\
&H_{\max 5\text{ MHz} < f \le 30\text{ MHz}} = C_{WS,I} \times I = 1{,}59 \times 10^{-4} \frac{1}{\text{m}} \times 2{,}0 \times 10^{-4}\text{ A} = 3{,}14 \times 10^{-8} \frac{\text{A}}{\text{m}} = -30\text{ dB}\frac{\mu\text{A}}{\text{m}}
\end{aligned} \tag{D.4}$$

NOTE 1 The differential mode (DM) impedance of Z_{DM} = 100 Ω applied for the modelling is the impedance of the AMN to which the ELV lamp is connected during a conducted emission measurement. The actual DM impedance of a power source (driver) to which the ELV lamp is connected will differ from this value and is generally unknown. Furthermore, the overall DM impedance is the sum of the DM impedance of the AMN (100 Ω) and the impedance in series of the disturbance source inside the ELV lamp. The latter is generally unknown, but 0 Ω certainly represents the worst case.

As Table 9 of CISPR 15:2018 also contains magnetic field strength limits for lighting equipment, a comparison can be made to show, that field strength estimated with Biot-Savart–law that is applied to differential mode current is not relevant. Figure D.5 shows the magnetic field limits in 3 m distance as required in Table 9 of CISPR 15:2018. Those are converted to 10 m distance using the conversion factors laid out in Table B.5. Note that the conversion factors are derived by assuming a small magnetic dipole source on a perfectly conductive ground. The values can now be compared to the value given in Equation (D.4). The Biot-Savart values are below the converted limit for all frequencies in question.

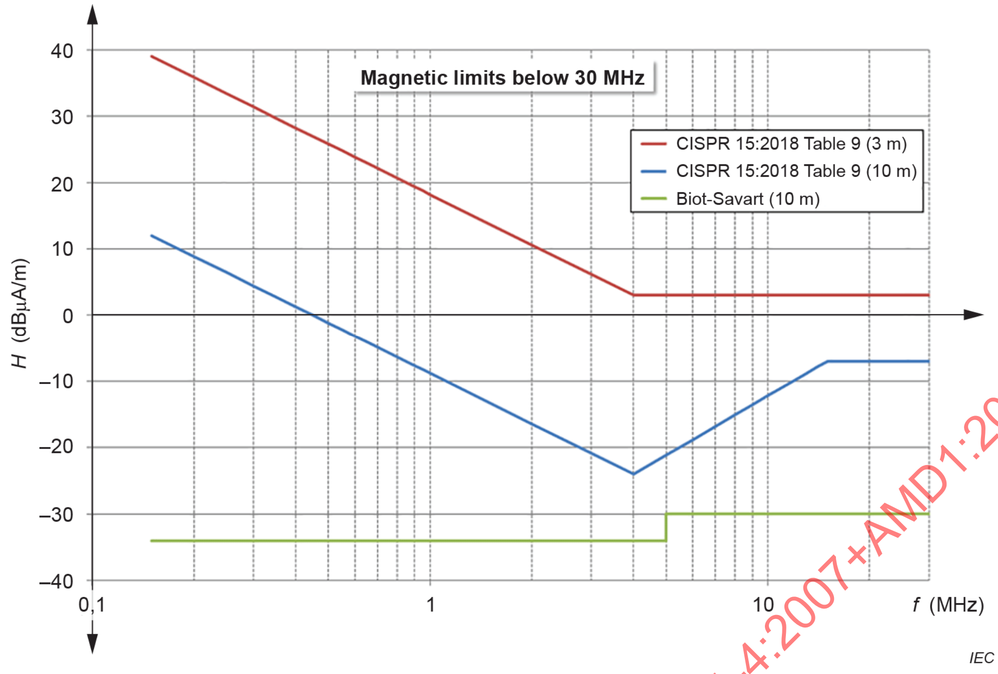


Figure D.5 – Field strength derived by Biot-Savart-law applied to a differential mode current in comparison with the values in CISPR 15:2018, Table 9 (3 m) converted to 10 m

This field strength is rather low, but can be dominant in some cases. This can be considered by ensuring that none of the coupling factors used in this document falls below the coupling factor C_{WS} of this Biot-Savart derivation. For convenience the coupling factor defined in Equation (D.3) is converted to electric field units and power feed (see Equation (D.5)).

$$C_{WS} = \frac{E}{\sqrt{P}} = \frac{Z_0 \times H}{\sqrt{I^2 \times R}} = \frac{Z_0 \times H}{\sqrt{R} \times I} = C_{WS,I} \times \frac{Z_0}{\sqrt{R}} = 1{,}59 \times 10^{-4} \frac{1}{m} \frac{377\Omega}{\sqrt{100\Omega}} = 0{,}006 \frac{\sqrt{\Omega}}{m} \quad (D.5)$$

A smaller coupling factor results in a higher limit value allowance for a given maximum disturbance field strength. To account adequately for the effect of wire separation the calculated value of Equation (D.5) shall be used instead of the coupling factor if any of the coupling factors derived for consideration of other effects (i.e. capacitive coupling to remote ground, see Clause D.3) is below the calculated value of Equation (D.5).

NOTE 2 The coupling factors used in Clause D.2 refer to the input power inserted in differential mode with respect to the differential mode impedance presented by an AMN. The voltage limit calculated is therefore a differential mode voltage and needs to be corrected by subtracting 6 dB, as usually only one unsymmetrical voltage at a time is measured with the AMN.

D.3 Capacitive coupling to remote ground

The effect of capacitive interaction with remote ground is predominant over branching or differences in wire lengths. Only the predominant effect for unbalance, leading to radiation of the ELV lighting installation needs to be considered. To describe the effect, a coupling factor of the electrical field $C_{CAP,EP}$ to a given inserted power and a second coupling factor for the magnetic field $C_{CAP,HP}$ is defined as given in Equation (D.6).

$$E = C_{CAP,EP} \times \sqrt{P} \wedge H = C_{CAP,HP} \times \frac{1}{120\pi} \times \sqrt{P} \quad (D.6)$$

They differ, because for most frequencies the victim receiver is in the near field zone of the radiating lighting installation.

For the calculation of the respective coupling factors, simulations with a Maxwell equation solver (i.e. NEC2, FEKO, Concept) can be carried out, using a representative lighting installation. Here besides the lighting installation itself, the capacitive load is simulated as well. As one possible worst case a conductive metal element, which itself is grounded, is in close proximity to one of the wires. This is used to represent the practical case of the wire lying in a metallic wire tray.

Figure D.6 shows the worst case scenario the radiation model is based on.

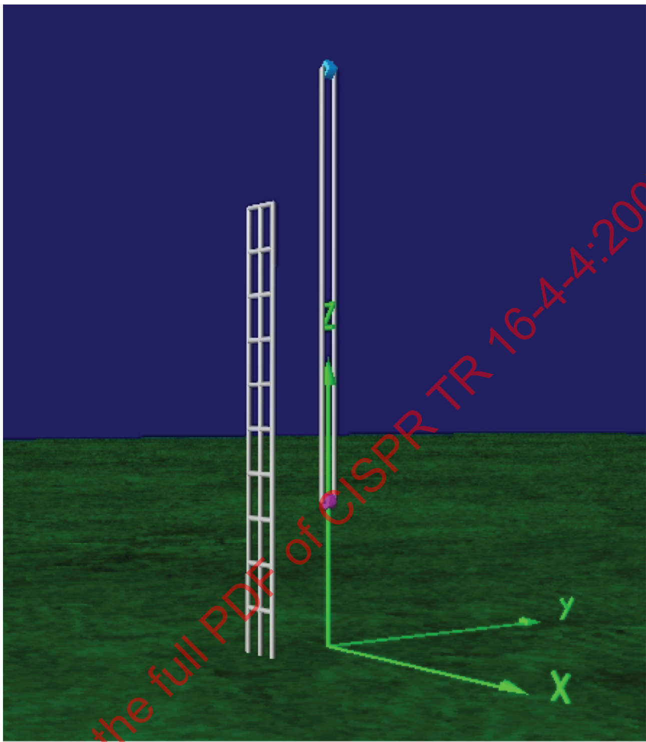


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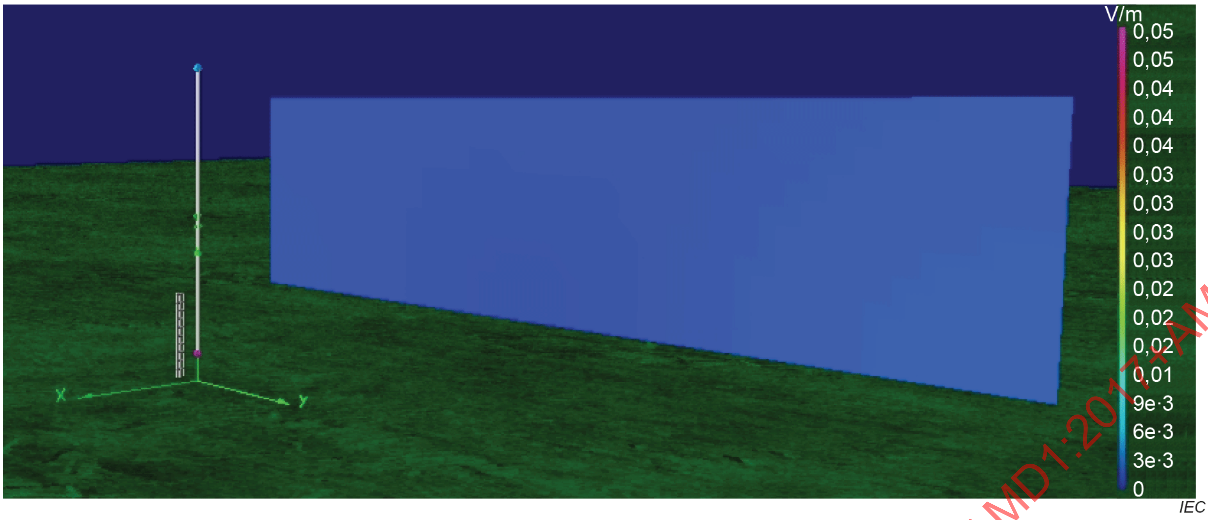
Figure D.6 – Principal model used for the simulations

It is represented by a vertical two wire line with a length of 10 m which starts 1 m above the ground. The two parallel wires have a distance of *d* = 10 cm to each other and are fed with a differential mode current at the bottom of the wire system in a constant power condition by impedance match. The upper end is terminated with a resistor which equals the value of the line impedance of the wire (572 Ω).

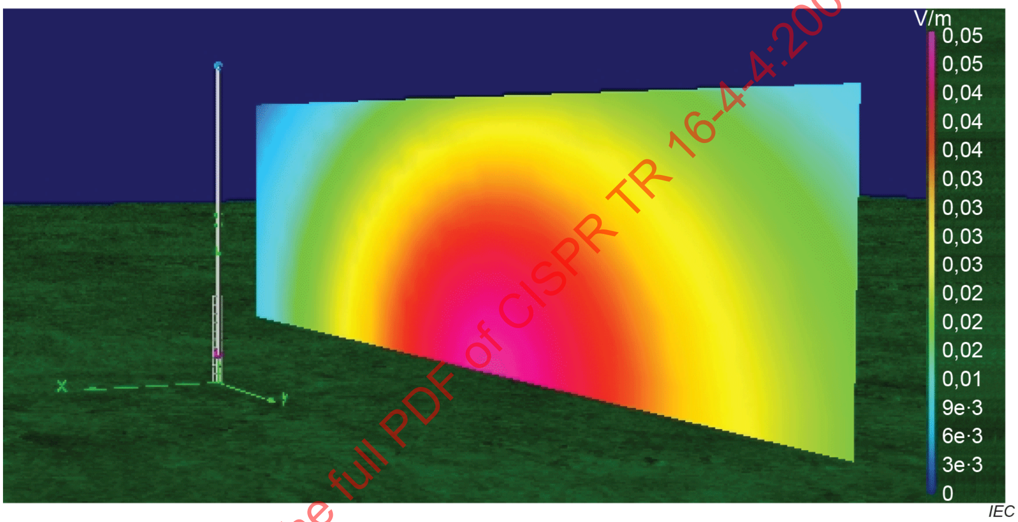
NOTE 1 For illustration purposes, only the two wire line is shortened to a 3 m length to fit well in this picture and the conductive vertical plane, which is connected to the ground, is much closer to the two wire system in the simulation than depicted in Figure D.6.

To introduce unbalance, a conductive vertical plane of 30 cm width is placed perpendicularly to the two wire lines at a distance of 5 cm from the facing wire. Since the distance of that plane to the other wire is now 15 cm, the capacity to ground is much higher from the closer wire than from the remote wire, thus unbalancing the system. Furthermore this conductive plane is connected to the ideally conducting ground plane, which on the whole represents a worst case model for the assessment of the coupling factor.

Figure D.7 shows the field strength distribution on a plane at a distance of 10 m from the installation.



a) Capacitive load distance to wires 1 m



b) Capacitive load distance to wires 5 cm

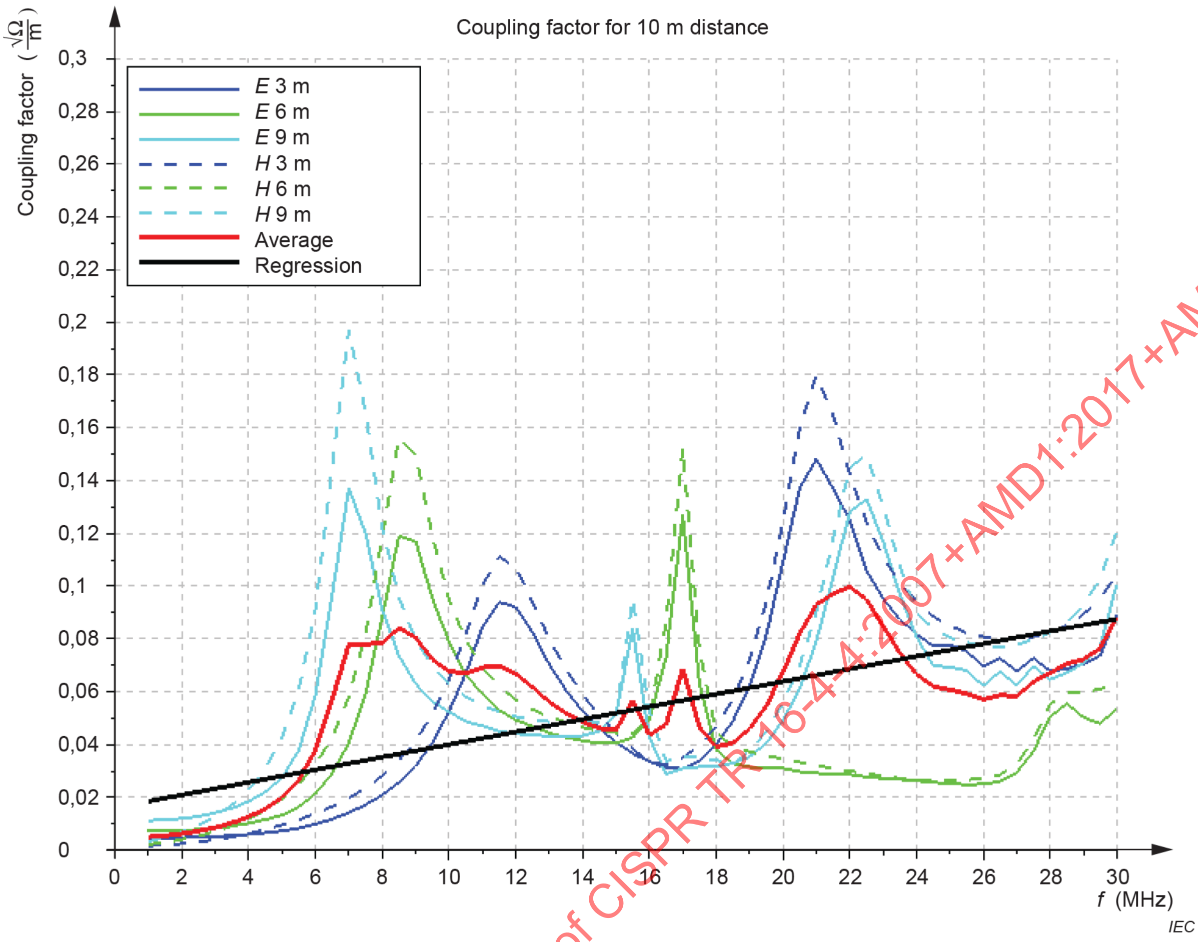
Figure D.7 – Electric field distribution (at 10 MHz) on a vertical plane at a distance of 10 m from the vertical two wire system

When the capacitive load is placed at a distance of one meter from the two wire system almost no field is detectable (Figure D.7a)). Placing the capacitive load only 5 cm away from the wire leads to a quite different result (Figure D.7b)). It can be clearly seen that the introduction of an unbalance to the system dominates the radiation characteristics.

This again confirms the statement that an unbalance of the system to remote ground has a large impact while direct radiation caused by the differential mode current in the corresponding wires can be neglected in these considerations.

The simulation is repeated for different sizes of the capacitive load. In the first simulation the capacitive plate is only 3 m high. As this length influences the frequency dependence of the coupling factor due to resonance effects, it is repeated with a length of 6 m and 9 m.

Figure D.8 shows the final result of the coupling factor as a function of frequency. Depending on the length of the capacitive plate, the maxima are located at different frequencies but of the same magnitude. A general trend can be observed, as low frequencies are radiated slightly less effectively, while for the upper frequencies the wire system becomes a more effective radiator.



The dotted lines show the magnetic field case, where for comparability, the result was multiplied by 120 × π Ω.

Figure D.8 – Coupling factor result for 3 different scenarios

To find a closed formula for the coupling factor, all calculated factors were averaged (red line in Figure D.8) and a linear regression line was calculated, which is described by Equation (D.7).

$$C_{CAP}(f)\left[\frac{\sqrt{\Omega}}{\text{m}}\right] = 0{,}00238 \times f(\text{MHz}) + 0{,}01617 \qquad \text{(D.7)}$$

NOTE 2 For all frequencies considered the coupling interaction is stronger than the effect of the wire system described in Clause D.2, therefore only C_{CAP} is considered in the calculation for limit validation.

D.4 Consideration of probability factors

D.4.1 General

The disturbance will not actually occur in all cases, due to the fact that victim and source need to coincide in time, location and frequency. These three probability factors are assumed to play the major role in a disturbance scenario from ELV lighting installations.

When logarithmic probability factors are calculated, the linear probability shall be converted to a logarithm in base 10 and multiplied with a factor of 10, which originates from the signal-to-disturbance ratio defined as ratio of received signal power to the received disturbance power. Solely for distance ratios a factor of 20 shall be used.

NOTE Building attenuation was not considered as for the frequency range up to 30 MHz no reliable data is available. Due to the relatively large wavelength, the penetration depth is large compared to the thickness of the walls. Unless enforced concrete walls are used, the electromagnetic wave are only slightly or not attenuated.

D.4.2 Probability factor for time coincidence μ_{P7} and σ_{P7}

The disturbance can only occur at times, when the lighting installation is in operation. It can be assumed that most lamps are only used when there is no daylight available, resulting in an overall usage of 12 h per day. This leads to the probability of 50 % and the resulting factor as shown in Equation (D.8).

$$\mu_{P7} = -10 \times \log_{10}\left(\frac{12}{24}\right) = 3\text{ dB} \tag{D.8}$$

However, different night time lengths occur in the course of the year. Therefore a need for light varying between 4 h to 20 h per day following a uniform distribution is assumed. The respective standard deviation can be calculated as shown in Equation (D.9).

$$\sigma_{P7} = -\frac{10 \times \log_{10}\left(\frac{4}{24}\right) - 10 \times \log_{10}\left(\frac{20}{24}\right)}{2 \times \sqrt{3}} = 2\text{ dB} \tag{D.9}$$

D.4.3 Probability factor for location coincidence μ_{P8} and σ_{P8}

It is assumed, that every second household uses ELV lighting somewhere on the premises. However, the coupling model using wire line separation distances of 10 cm represents the worst case. Such systems are more sparsely populated in residential areas and it was suggested to assume only one out of eight installations would be of such type. This could vary insofar as every second household or only every twentieth household has such an installation, which leads to the values given in Equation (D.10).

$$\mu_{P8} = -10 \times \log_{10}(0{,}5 \times 0{,}125) = 12\text{ dB}$$

$$\sigma_{P8} = -\frac{10 \times \log_{10}\left(\frac{1}{2}\right) - 10 \times \log_{10}\left(\frac{1}{20}\right)}{2} = 5\text{ dB} \tag{D.10}$$

It was assumed that there is only one amateur station in every thousand households in a world average. Therefore an additional location coincidence was applied in the case of the amateur radio service.

$$\begin{aligned} \mu_{P8\text{ AmaR}} &= -10\log_{10}(0{,}001) = 30\text{ dB} \\ \sigma_{P8\text{ AmaR}} &= -\frac{10 \times \log_{10}(0{,}0005) - 10 \times \log_{10}(0{,}005)}{2} = 5\text{ dB} \end{aligned} \tag{D.11}$$

D.4.4 Probability factor for frequency coincidence μ_{P4} and σ_{P4}

No data on the frequency probability in case of the ELV lighting installations is available at present. Therefore the frequency coincidence is assumed to be unity which represents the worst case.

$$\mu_{P4} = 0\ \text{dB}$$
$$\sigma_{P4} = 0\ \text{dB} \quad (D.12)$$

D.5 Calculation of the limit

To fulfil the primary task of verification of the limits for ELV lamps as specified since the publication of CISPR 15:2013/AMD1:2015 [14], this clause presents a calculation based on a simulation of the coupling factor with a worst case model. The following list gives an overview of the parameters needed for the verification for a given radio service or application. Subsequently, the assumptions made to gain concrete values for the calculation will be described in detail.

- wanted signal field strength E_w;
- required S/N resp. protection ratio R_P;
- probability for time coincidence P_7;
- probability for location coincidence P_8;
- probability for frequency coincidence inclusive harmonics P_4;
- global coupling factor C_{LI}.

The maximum permissible interference field strength E_{ir} for the disturbance is determined by subtracting the protection ratio from the wanted signal field strength of the radio application. Usually these parameters are given in ITU-R publications, but for simplicity CISPR has collected and published the results in the "Radio Services Database" on the IEC website under the EMC technology sector. There the radio application to be protected is chosen and the permissible disturbance field strength E_{ir} is calculated. This has to be evaluated for every entry in the radio services database resulting in a function for E_{ir} dependent on the frequency.

If the bandwidth of the radio service is equal to the measurement bandwidth nothing needs to be done with respect to correction of maximum tolerable noise. In the case of lower bandwidth of the radio service, as in the case of the amateur radio services, the bandwidth shall be corrected according to Subclause 5.6.6.2 using Equation (D.13).

$$E_{ir,corr} = E_{ir} + 10 \times \log\left(\frac{b_{victim}}{b_{measurement}}\right) \quad (D.13)$$

NOTE The document is based on the assumption that the signal characteristics of disturbances caused by ELV systems in the worst case are continuous, leading to equivalent outputs of all CISPR detectors.

The permissible interference field strength E_{Limit} with the consideration of probability factors is calculated by Equation (D.14).

$$E_{Limit} = E_{ir,corr} + \mu_{P4} + \mu_{P7} + \mu_{P8} - t_\alpha \times \sqrt{\sigma_{P4}^2 + \sigma_{P7}^2 + \sigma_{P8}^2} \quad (D.14)$$

According to the relationships between the quantities given in Equation (D.6), the maximum permissible disturbance power P_L can be derived by combining the function E_{Limit} (Equation (D.14)) with the coupling factor given by Equation (D.7) (as coupling interaction caused by the wire system can be neglected as shown in Clause D.3) for each frequency resulting in Equation (D.15).

$$P_{\mathrm{L}} = \frac{E_{\mathrm{Limit}}{}^{2}}{C_{\mathrm{LI}}^{2}} \tag{D.15}$$

The disturbance voltage limit for type tests on ELV lamps at test sites U_{Limit} can be derived using Equation (D.16).

$$\begin{aligned} U_{\mathrm{Limit}}\left[\mathrm{V}\right] &= \sqrt{100\Omega \times P_{\mathrm{L}}\left[\mathrm{W}\right]} \\ U_{\mathrm{Limit}}\left[\mathrm{dB\mu V}\right] &= 20 \times \log_{10}\left(\frac{U_{\mathrm{Limit}}\left[\mathrm{\mu V}\right]}{1\mathrm{\mu V}}\right) \end{aligned} \tag{D.16}$$

Table D.1 gives an overview of the most important parameters for well-established radio services in the frequency range from 150 kHz to 30 MHz.

Table D.1 – Calculation of U_{Limit} for radio services between 150 kHz and 30 MHz

f [MHz]	E_{w} [dBµV/m]	R_{P} [dB]	Service	E_{ir} [dBµV/m]	μ_{P7} Time [dB]	μ_{P8} Location [dB]	μ_{P4} Frequency [dB]	E_{Limit} [dBµV/m]	C_{cap} [Ω/m]	P_{L} [dBm]	U_{Limit} [dBµV]
0,20	72	30	LF	42	3	12	0	52,5	0,017	-1,9	108,1
0,28	71	30	LF	41	3	12	0	51,5	0,017	-3,0	107,0
0,48	-1	10	AmaR	-11	3	42	0	33,1	0,017	-21,7	88,3
1,00	60	30	MF	30	3	12	0	40,5	0,019	-14,9	95,1
1,91	-3	10	AmaR	-13	3	42	0	31,1	0,021	-25,3	84,7
3,75	-6	10	AmaR	-16	3	42	0	28,1	0,025	-29,9	80,1
3,95	47	27	HF	20	3	12	0	30,5	0,026	-27,7	82,3
5,95	45	27	HF	18	3	12	0	28,5	0,030	-31,2	78,8
6,10	45	27	HF	18	3	12	0	28,5	0,031	-31,3	78,7
7,15	-8	10	AmaR	-18	3	42	0	26,1	0,033	-34,4	75,6
7,25	45	27	HF	18	3	12	0	28,5	0,033	-32,0	78,0
7,33	45	27	HF	18	3	12	0	28,5	0,034	-32,1	77,9
9,45	44	27	HF	17	3	12	0	27,5	0,039	-34,3	75,7
9,70	44	27	HF	17	3	12	0	27,5	0,039	-34,4	75,6
10,13	-10	10	AmaR	-20	3	42	0	24,1	0,040	-38,0	72,0
11,63	43	27	HF	16	3	12	0	26,5	0,044	-36,4	73,6
11,80	43	27	HF	16	3	12	0	26,5	0,044	-36,4	73,6
12,05	43	27	HF	16	3	12	0	26,5	0,045	-36,6	73,4
13,60	43	27	HF	16	3	12	0	26,5	0,049	-37,2	72,8
13,70	43	27	HF	16	3	12	0	26,5	0,049	-37,3	72,7
13,87	43	27	HF	16	3	12	0	26,5	0,049	-37,4	72,6
14,18	-11	10	AmaR	-21	3	42	0	23,1	0,050	-40,9	69,1
15,35	42	27	HF	15	3	12	0	25,5	0,053	-39,0	71,0
15,70	42	27	HF	15	3	12	0	25,5	0,054	-39,1	70,9
17,50	42	27	HF	15	3	12	0	25,5	0,058	-39,8	70,2
17,80	42	27	HF	15	3	12	0	25,5	0,059	-39,9	70,1
18,10	-12	10	AmaR	-22	3	42	0	22,1	0,059	-43,4	66,6
18,95	41	27	HF	14	3	12	0	24,5	0,061	-41,3	68,7
21,23	-13	10	AmaR	-23	3	42	0	21,1	0,067	-45,4	64,6
21,65	41	27	HF	14	3	12	0	24,5	0,068	-42,1	67,9

f [MHz]	E_w [dBµV/m]	R_P [dB]	Service	E_{ir} [dBµV/m]	μ_{P7} Time [dB]	μ_{P8} Location [dB]	μ_{P4} Frequency [dB]	E_{Limit} [dBµV/m]	C_{cap} [Ω/m]	P_L [dBm]	U_{Limit} [dBµV]
24,94	-14	10	AmaR	-24	3	42	0	20,1	0,076	-47,5	62,5
26,00	40	27	HF	13	3	12	0	23,5	0,078	-44,4	65,6
28,80	-16	10	AmaR	-26	3	42	0	18,1	0,085	-50,5	59,5

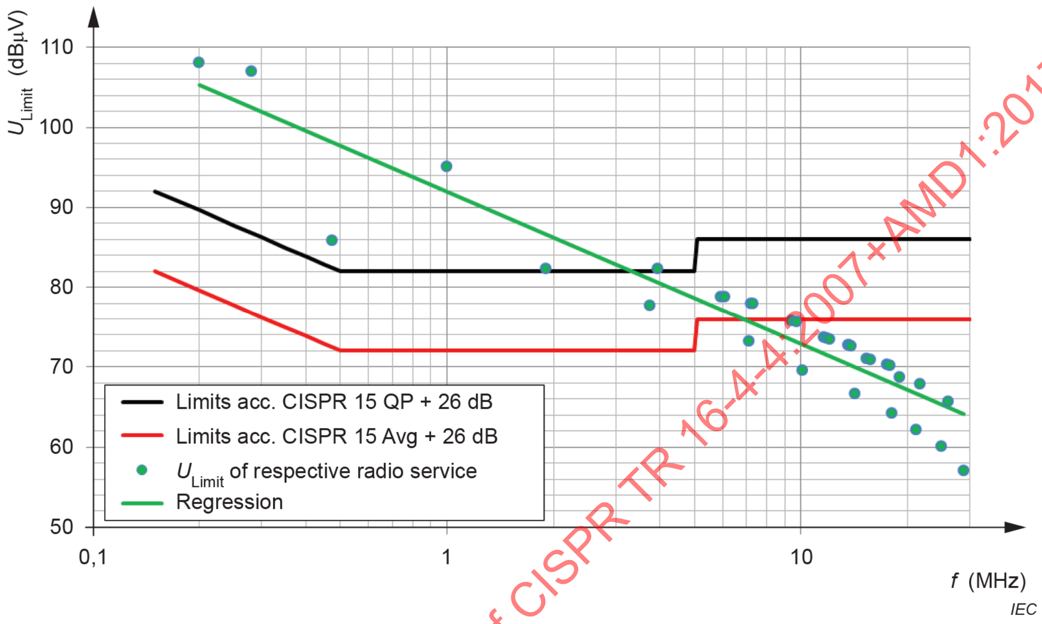


Figure D.9 – Overview of the calculated U_{Limit} values for radio services between 150 kHz and 30 MHz

From the analysis of the green dots in Figure D.9 (each representing a radio service from the radio service database) a frequency dependent limit line as drawn in green would be a logical choice. The line was derived by linear regression with the limit values against the logarithm of frequency leading to a limit of 107,7 dBµV at 150 kHz decreasing with logarithm of frequency to 63,8 dBµV at 30 MHz.

The presented model was developed based mainly on worst case assumptions and not validated by experiments. Moreover, probability factors were estimated from limited information..

From this calculation, it can be stated that many radio services in the frequency range above 5 MHz are not fully protected, while on the other hand, the existing limit line in the lower frequency range seems to be too strict.

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[11] CISPR 12, *Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers*

[12] CISPR 13, *Sound and television broadcast receivers and associated equipment – Radio disturbance characteristics – Limits and methods of measurement*

[13] CISPR 14 (all parts), *Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus*

[14] CISPR 15:2013, *Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment*
CISPR:2013/AMD1:2015[6]

[15] CISPR 16-1 (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1: Radio disturbance and immunity measuring apparatus*

[16] CISPR 16-2, (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2: Methods of measurement of disturbances and immunity*

6 CISPR 15:2013 and CISPR:2013/AMD1:2015 withdrawn.

[17] CISPR 16-3, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 3: CISPR technical reports*

[18] CISPR 16-4-1, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-1: Uncertainties, statistics and limit modelling – Uncertainties in standardised EMC tests*

[19] CISPR 18 (all parts), *Radio interference characteristics of overhead power lines and high-voltage equipment*

[20] CISPR 22, *Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement*

[21] CISPR 25, *Radio disturbance characteristics for the protection of receivers used on board vehicles, boats, and on devices – Limits and methods of measurement*

[22] ITU-R Recommendation BS.703, *Characteristics of AM sound broadcasting reference receivers for planning purposes*

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CISPR TR 16-4-4

Edition 2.2 2020-04
CONSOLIDATED VERSION

FINAL VERSION

colour inside

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

Specification for radio disturbance and immunity measuring apparatus and methods –
Part 4-4: Uncertainties, statistics and limit modelling – Statistics of complaints and a model for the calculation of limits for the protection of radio services

CISPR TR 16-4-4:2007-07+AMD1:2017-06+AMD2:2020-04 CSV(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

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FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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This consolidated version of the official IEC Standard and its amendments has been prepared for user convenience.

CISPR 16-4-4 edition 2.2 contains the second edition (2007-07) [documents CISPR/H/147/DTR and CISPR/H/153/RVC], its amendment 1 (2017-06) [documents CIS/H/313/DTR and CIS/H/319/RVC] and its amendment 2 (2020-04) [documents CIS/H/402/DTR and CIS/H/407A/RVDTR].

This Final version does not show where the technical content is modified by amendments 1 and 2. A separate Redline version with all changes highlighted is available in this publication.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

This second edition of CISPR 16-4-4, which is a technical report, has been prepared by CISPR subcommittee H: Limits for the protection of radio services.

This second edition of CISPR 16-4-4 contains two thoroughly updated Clauses 4 and 5, compared with its first edition. It also contains, in its new Annex A, values of the classical CISPR mains decoupling factor which were determined by measurements in real LV AC mains grids in the 1960s. It is deemed that these mains decoupling factors are still valid and representative also for modern and well maintained LV AC mains grids around the world.

The information in Clause 4 – Statistics of complaints and sources of interference – was accomplished by the history and evolution of the CISPR statistics on complaints about radio frequency interference (RFI) and by background information on evolution in radio-based communication technologies. Furthermore, the forms for collation of actual RFI cases were detailed and structured in a way allowing for more qualified assessment and evaluation of compiled annual data in regard to the interference situation, as e.g. fixed or mobile radio reception, or analogue or digital modulation of the interfered with radio service or application concerned.

The information in Clause 5 – A model for the calculation of limits – was accomplished in several ways. The model itself was accomplished in respect of the remote coupling situation as well as the close coupling one. Further supplements of this model were incorporated regarding certain aspects of the coupling path via induction and wave propagation (radiation) of classical telecommunication networks. Furthermore, the calculation model on statistics and probability underwent revision and was brought in line with a more modern mathematical approach. Eventually the present model was extended for a possible determination of CISPR limits in the frequency range above 1 GHz.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the stability date indicated on the IEC web site 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 4-4: Uncertainties, statistics and limit modelling – Statistics of complaints and a model for the calculation of limits for the protection of radio services

1 Scope

This part of CISPR 16 contains a recommendation on how to deal with statistics of radio interference complaints. Furthermore it describes the calculation of limits for disturbance field strength and voltage for the measurement on a test site based on models for the distribution of disturbances by radiated and conducted coupling, respectively.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-161*, International Electrotechnical Vocabulary (IEV) – Part 161: Electromagnetic compatibility* (available at http://www.electropedia.org)

CISPR 11, *Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement*

CISPR 16-4-3, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-3: Uncertainties, statistics and limit modelling – Statistical considerations in the determination of EMC compliance of mass-produced products*

CISPR 15:2018, *Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-161 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
complaint
request for assistance made to the RFI investigation service by the user of a radio receiving equipment who complains that reception is degraded by radio frequency interference (RFI)

3.1.2
RFI investigation service
institution having the task of investigating reported cases of radio frequency interference and which operates at the national basis

EXAMPLE Radio service provider, CATV network provider, administration, regulatory authority.

3.1.3
source
any type of electric or electronic equipment, system, or (part of) installation emanating disturbances in the radio frequency (RF) range which can cause radio frequency interference to a certain kind of radio receiving equipment

3.2 Symbols and abbreviated terms

E_{ir}	permissible interference field strength at the point A in space where the antenna of the victim receiver is located – without consideration of probability factors
E_{Limit}	permissible interference field strength at the point A in space where the antenna of the victim receiver is located – with consideration of probability factors
R_P	protection ratio
C_{PV}	coupling factor describing the proportionality of the field strength E with the square root of the power P injected as common mode into the radiating structure by the apparatus (GCPC)
Group A	defined PV generator group for single-family detached houses
Group B	defined PV generator group for multi-storey buildings with flat roof tops
Group C	defined PV generator group for sun tracking supports (“trees”)
Group D	defined PV generator group for large barns in the countryside
ρ_i	probability of an individual PV generator being a member of Group i
$\bar{C}_{PV}$	group-independent mean value for the coupling factor
P_S	disturbance power emitted by a GCPC with the complex source impedance Z_S
P_L	power injected into the PV generator eventually radiated via that installation
P_{TC}	disturbance power determined at the DC-AN on a standardized test site according to CISPR 11 with fixed impedance Z_{TC} = 150 Ω
U_{Limit}	permitted disturbance voltage limit
P_7	probability for time coincidence (μ_{P7} in dB)
P_8	probability for location coincidence (μ_{P8} in dB)
P_4	probability for frequency coincidence inclusive harmonics(μ_{P4} in dB)
m_L	mismatch loss in use case (between the GCPC with complex source impedance Z_S and the PV generator with complex load impedance Z_L)
m_{TC}	mismatch loss in test case (between the GCPC with complex source impedance Z_S and the DC-AN according to CISPR 11 with measurement impedance fixed to Z_{TC} = 150 Ω)
AMN	artificial mains network
CM	common mode
DC-AN	DC artificial network
DM	differential mode

GCPC grid connected power converter

S/N noise power/signal power

4 Statistics of complaints and sources of interference

4.1 Introduction and history

The previous edition of CISPR 16-4-4 contained, in its Clause 4, a complete reprint of CISPR Recommendation 2/3 on statistics of complaints and sources of interference. However, due to modern technological evolution in radio systems directed towards introduction of digital radio services, and due to increasing use of mobile and portable radio appliances by the public, the traditional CISPR statistics of complaints on radio frequency interference are experiencing a decreasing significance as an indicator of the quality of standardisation work for the protection of radio services and applications. That is why related information in this edition of CISPR 16-4-4 is reduced to the necessary minimum allowing interested parties to continue their complaint-based collation of data on an annual basis.

In order to accommodate the evolution in modern radio technology and mobile and portable use of radio receiving equipment, it may be necessary to replace or to gather the complaints-based CISPR statistics by other more modern statistics or means. These new statistics should be based on a systematic annual collation of data about degradation of quality of radio services and reception due to electromagnetic disturbances occurring in the environment. These data will have to be collected and processed, however, primarily by the radio service providers themselves.

4.2 Relationship between radio frequency interference and complaints

Whatever the radio system involved, official complaints usually represent only a small subset of all occurring interference situations. Occasional interference generally does not lead to an official complaint if its duration is brief or if it happens only once in a while. It is only when the same interference situation occurs repetitively that an official complaint is reported. This situation also greatly depends on the conditions of use (fixed or mobile) of the victim radio system.

4.2.1 Radio frequency interference to a fixed radio receiver

Before the wide development of portable radio devices, radio systems that suffered from interference were generally used in fixed locations. This is the case, for example for a TV set in a flat or home: if this TV set is regularly interfered with by radiation or conduction from other equipment located inside or just outside the house, then it is probable that a complaint will be issued. The same applies if a satellite antenna, a fixed radio link, or a cellular phone base station suffers from radio frequency interference.

4.2.2 Radio frequency interference to a mobile radio receiver

The multiplication of portable radio systems such as cellular phones and short range radio systems has changed the conditions regarding interference situations and interference complaints. The ability for the user to move makes it easier to resolve a particular interference case, but makes it more difficult to recognise that an interference case has actually occurred.

4.2.3 Consequences of the move from analogue to digital radio systems

In addition to the conditions of use of the victim radio system, technological evolution in radio services with successive phasing out of analogue and exponential growth of digital applications also has consequences on the number of reported interference cases.

If a digital mobile phone or a wireless LAN receiver cannot receive the signal from the nearest base station or access point because of an unwanted emission from a nearby equipment, the user will never suspect this equipment and will not even consider the possibility of an interference occurring. He will assume that the coverage of the network is poor and will move to another place to make his call or to get his connection. Furthermore, as these systems are generally frequency agile, if one channel is interfered with, the system will choose another channel, but if all other channels are occupied, then the phone will indicate that the network is busy, and once again, the user will think the network capacity is not large enough to accommodate his call, but he will never suspect an EMC problem.

Generally for analogue systems, one can hear the interference. With digital and mobile systems, interference is much less noticeable (muting in audio reception, or frozen images on the TV set for DVB). In addition, modern digital modulations implement complex escape mechanisms (data error correction, frequency agile systems, etc.) so that the system can already be permanently affected from an EMC point of view before an interference case is actually detected.

4.3 Towards the loss of a precious indicator: interference complaints

The evolutions detailed above – generalisation of mobile use of radio receivers and the move from analogue to digital radio services – will not reduce the number of interference situations, but continues to decrease the probability of getting significant numbers of interference complaints indicating an existing EMC problem. So, along with the growing development of portable digital radio devices, the usefulness of traditional interference complaints statistics to support the CISPR work will continue to diminish in importance.

4.4 CISPR recommendations for collation of statistical data on interference complaints and classification of interference sources

Considering

a) that RFI investigation services may whish to continue publication of statistics on interference complaints;

b) that it would be useful to be able to compare the figures for certain categories of sources;

c) that varied and ambiguous presentation of these statistics often renders this comparison difficult,

CISPR recommends

(1) that the statistics provided to National Committees should be in such a form that the following information may be readily extracted:

(1.1) the number of complaints as a percentage of the total number of sound broadcast receivers or television broadcast receivers or other radio communication receivers in operation in a certain country, or region;

(1.2) the relative aggressivity of the various sources of interference in the different frequency bands;

(1.3) the comparison of the interference caused by the same source in different frequency bands;

(1.4) the effectiveness of limits (CISPR or national) and other counter-measures on items (1.1), (1.2), and (1.3);

(1.5) the number of sources of the same type involved in a certain interference case. Interference may be caused by a group of devices, for example, a number of fluorescent lamps on one circuit. In such cases, the number to be entered into the statistics is determined by the RFI investigation service.

NOTE To facilitate comparison of statistics, the method used to determine the number of sources should be stated.

One source may cause many complaints and one complaint may be caused by more than one source. Therefore it is clear that the number of sources and the number of complaints against any classification code may not be related.

For the purpose of these statistics, active generators of electrical energy and apparatus and installations which cause interference by secondary effects (secondary modulation) are included. See also appliances of category B in Table 1;

(1.6) causes of complaints not related to a source, as e.g. unsatisfactory radio reception due to a lack of immunity of the radio receiving installation or a lack of coverage with wanted radio signals, see also appliances of category K in Table 1;

(2) that statistics should cover a complete calendar year; they should whenever possible be presented in the following form, see standard forms in Figures 1a to 1d, without necessarily employing more detailed categories than listed in Table 1. It is however not intended to exclude further subdivisions; these may be desirable, but they should fit into the scheme of the standard forms set out below; the code numbers refer to the items listed in Table 1.

4.5 Forms for statistics of interference complaints

<table>
<tr><td colspan="2">1</td><td colspan="9">Radio services with analogue modulation</td></tr>
<tr><td colspan="2">1.1</td><td colspan="9">Fixed or stationary radio reception</td></tr>
<tr><td colspan="5">Source of interference
or other cause of complaint</td><td colspan="6">Number of complaints per radio service from each source</td></tr>
<tr><td colspan="3" rowspan="3">Classification code</td><td rowspan="3">Description</td><td rowspan="3">Total number in each identification</td><td colspan="5">Broadcasting [a]</td><td>Other services [b]</td></tr>
<tr><td colspan="2">Sound [c]</td><td colspan="3">Television [c]</td><td></td></tr>
<tr><td>LF/ MF/ HF</td><td>II</td><td>I</td><td>III</td><td>IV/V</td><td></td></tr>
<tr><td>A</td><td>1
2</td><td>1
1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">etc. as indicated in Table 1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1.1</td><td colspan="3">Fixed or stationary radio reception, analogue modulation</td><td>Totals</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

a LF = low radio frequency (long waves);
MF = medium radio frequency (medium waves);
HF = high radio frequency (short waves).
These three bands may either be grouped together, as shown, or dealt with separately.
II = Band II (VHF/sound broadcasting);
I = Band I (VHF/television broadcasting);
III = Band III (VHF/television broadcasting);
IV/V = Band IV/V (UHF/television broadcasting).

b The service and band affected should be stated.

c At the time of receipt of complaints of interference, i.e. before they have been investigated fully, it may not be possible to apportion the complaints accurately to the various broadcasting services. If this is so, then the number of complaints should be stated separately for sound broadcasting and television broadcasting.

IEC 1182/07

Figure 1a – Standard form for statistics on interference complaints recommended for radio services with analogue modulation and fixed or stationary radio reception

1	**Radio services with analogue modulation**									
1.2	**Mobile or portable radio reception**									
Source of interference or other cause of complaint					**Number of complaints per radio service from each source**					
Classification code			**Description**	**Total number in each identification**	**Broadcasting** [a]					**Other services** [b]
					Sound [c]		**Television** [c]			
					LF/ MF/ HF	**II**	**I**	**III**	**IV/V**	
A	1	1								
	2	1								
		etc. as indicated in Table 1								
1.2	Mobile or portable radio reception, analogue modulation			Totals						

a LF = low radio frequency (long waves);
MF = medium radio frequency (medium waves);
HF = high radio frequency (short waves).
These three bands may either be grouped together, as shown, or dealt with separately.
II = Band II (VHF/sound broadcasting);
I = Band I (VHF/television broadcasting);
III = Band III (VHF/television broadcasting);
IV/V = Band IV/V (UHF/television broadcasting).

b The service and band affected should be stated.

c At the time of receipt of complaints of interference, i.e. before they have been investigated fully, it may not be possible to apportion the complaints accurately to the various broadcasting services. If this is so, then the number of complaints should be stated separately for sound broadcasting and television broadcasting.

IEC 1183/07

Figure 1b – Standard form for statistics on interference complaints recommended for radio services with analogue modulation and mobile or portable radio reception

2	**Radio services with digital modulation**									
2.1	**Fixed or stationary radio reception**									
Source of interference or other cause of complaint					**Number of complaints per radio service from each source**					
Classification code			**Description**	**Total number in each identification**	**Broadcasting** [a]					**Other services** [b]
					Sound [c]		**Television** [c]			
					LF/ MF/ HF	**II**	**I**	**III**	**IV/V**	
A	1	1								
	2	1								
		etc. as indicated in Table 1								
2.1	Fixed or stationary radio reception, digital modulation			Totals						

a LF = low radio frequency (long waves);
MF = medium radio frequency (medium waves);
HF = high radio frequency (short waves).
These three bands may either be grouped together, as shown, or dealt with separately.
II = Band II (VHF/sound broadcasting);
I = Band I (VHF/television broadcasting);
III = Band III (VHF/television broadcasting);
IV/V = Band IV/V (UHF/television broadcasting).

b The service and band affected should be stated.

c At the time of receipt of complaints of interference, i.e. before they have been investigated fully, it may not be possible to apportion the complaints accurately to the various broadcasting services. If this is so, then the number of complaints should be stated separately for sound broadcasting and television broadcasting.

IEC 1184/07

Figure 1c – Standard form for statistics on interference complaints recommended for radio services with digital modulation and fixed or stationary radio reception

2	**Radio services with digital modulation**								
2.2	**Mobile or portable radio reception**								
Source of interference or other cause of complaint					**Number of complaints per radio service from each source**				
Classification code			**Description**	**Total number in each identification**	**Broadcasting** [a]				**Other services** [b]
					Sound [c]		**Television** [c]		
					LF/ MF/ HF	**II**	**I**	**III**	**IV/V**
A	1	1							
	2	1							
		etc. as indicated in Table 1							
2.2	Mobile or portable radio reception, digital modulation			Totals					

a LF = low radio frequency (long waves);
MF = medium radio frequency (medium waves);
HF = high radio frequency (short waves).
These three bands may either be grouped together, as shown, or dealt with separately.
II = Band II (VHF/sound broadcasting);
I = Band I (VHF/television broadcasting);
III = Band III (VHF/television broadcasting);
IV/V = Band IV/V (UHF/television broadcasting).

b The service and band affected should be stated.

c At the time of receipt of complaints of interference, i.e. before they have been investigated fully, it may not be possible to apportion the complaints accurately to the various broadcasting services. If this is so, then the number of complaints should be stated separately for sound broadcasting and television broadcasting.

IEC 1185/07

Figure 1d – Standard form for statistics on interference complaints recommended for radio services with digital modulation and mobile or portable radio reception

Figure 1 – Standard forms for statistics on interference complaints

For RFI investigation services which would like to issue reports on statistics of interference complaints it is recommended to use the classification of interference sources set out in Table 1. Use of this classification will facilitate comparison of RFI situations observed in different countries.

Table 1 – Classification of sources of radio frequency interference and other causes of complaint

Classification code	Description of the source
A	**Industrial, scientific, and medical (ISM) RF apparatus (CISPR 11)**
A.1	Industrial, scientific, and medical (ISM) RF apparatus (group 2) inclusive microwave ovens and RF lighting appliances
A.2	Other industrial or similar apparatus (group 2) as e.g. arc welding equipment or spark generating apparatus (EDM), etc.
A.3	Other industrial or similar apparatus (group 1) as e.g. generators, motors, convertors, semiconductor controlled devices, etc.
B	**Electric power supply, distribution and electric traction (CISPR 11, CISPR 18)**
B.1	Power supply installations (AC or DC voltages exceeding 100 kV) as e.g. overhead power lines, generating and switching stations, converting stations, etc.
B.2	Power supply installations (AC or DC voltages 1 kV to 100 kV) as e.g. overhead power lines, generating and switching stations, converting stations, etc.
B.3	Low voltage (LV) power supply and distribution (AC or DC voltages up to 1 kV)
B.4	Electric traction as e.g. for railways, tramways, or trolley buses
C	**Low power appliances as normally used in households, offices and small workshops (CISPR 14)**
C.1	Motors in household appliances e.g. in electric tools, vacuum cleaners, etc.
C.2	Contact devices, thermostats, etc.
C.3	Semiconductor controlled appliances (less than 1 kW load)
D	**Gaseous discharge and other lamps and luminaries (CISPR 15)**
	Fluorescent lamps and luminaries, neon advertising signs, self-ballasted lamps, etc.
E [a]	**Radio broadcast receiving installations (CISPR 13, CISPR 25)**
E.1	Sound broadcast receivers for fixed or mobile use
E.2	Television broadcast receivers for fixed or mobile use
E.3	Cable television installations (CATV)
F [a]	**Radio communication systems (ITU Recommendations)**
F.1	Radio broadcast or communication transmitters for fixed or mobile use
F.2	Radio communication receivers for fixed or mobile use
G	**Ignition systems of internal combustion engines (CISPR 12)**
	Cars, motor bikes, boats, trucks, etc. if propelled by electrical means or internal combustion engines or both, exclusive electric traction vehicles
H	**Information and communication technology (ICT) appliances (CISPR 22)**
H.1	Wire-bound telecommunication terminal equipment (TTE) and telecommunication equipment (TE) in the infrastructure of networks as e.g. in telecommunication centres, wire-bound LAN, etc.
H.2	Data processing equipment (DPE) such as e.g. computers and ancillary equipment
H.3	Radiation from wire-bound telecommunication networks
J	**Identified sources other than those specified (IEC 61000-6-3 and IEC 61000-6-4)**
K	**Other causes of complaint**
K.1	Lack of immunity of radio receiving installations or other appliances
K.2	Lack of coverage of wanted radio service (weak or faulty wanted signals)

[a] Only those complaints belong to the statistics where a radio broadcast receiving installation (E) or a component of a radio communication system (F) was identified as causing the interference.

5 A model for the calculation of limits

5.1 Introduction

A harmonized method of calculation is an important precondition for the efficient discussion of CISPR limits by National Committees and the adoption of CISPR publications.

5.1.1 Generation of EM disturbances

CISPR publications are developed for protection of radio communications and often several types of radio networks are to be protected by a single emission limit.

Most electrotechnical equipment has the potential to interfere with radio communications. Coupling from the source of electromagnetic disturbance to the radio communications installation may be by radiation, induction, conduction, or a combination of these mechanisms. Control of the pollution of the radio spectrum is accomplished by limiting at the source the levels of appropriate components of the electromagnetic disturbances (voltage, current, field strength, etc.). The choice of the appropriate component is determined by the mechanism of coupling, the effect of the disturbance on radio communications installations and the means of measurement available.

5.1.2 Immunity from EM disturbances

Most radio receiving equipment has the potential to malfunction as the result of being subjected to EM disturbances.

Protection of equipment is accomplished by hardening the appropriate disturbance entry route except for the antenna input port, for in-band disturbances. The choice is determined by the mechanism of coupling, the effect of the disturbance on the electronic equipment and the means of measurement available.

5.1.3 Planning a radio service

Before planning a radio communication service, it is necessary to decide upon the reliability of obtaining a predetermined quality of reception. This condition can be expressed in terms of the probability of the actual signal-to-interference ratio R at the antenna input port of a receiver being greater than the minimum permissible signal-to-interference ratio R_p needed to get a predetermined quality of reception α. That is:

$$P\left[R(\mu_R;\sigma_R) \geq R_p\right] = \alpha$$

where

$P[\ ]$ is the probability function;

$R(\mu_R;\sigma_R)$ is the actual signal-to-interference ratio as a function of its mean value (μ_R) and standard deviation (σ_R);

R_p is the minimum permissible signal-to-interference ratio (protection ratio);

α is a specified value representing the reliability of communications.

This probability condition is the basis for the method of determining limits.

5.2 Probability of interference

In order to make recommendations to protect adequately the radio communications systems of interest to the ITU, considerable attention is paid within CISPR to the probability of interference occurring. The following is an extract from CCIR Report 829 [1].

5.2.1 Derivation of probability of interference

The Radio Regulations, Volume 1, Chapter I, Definition 1.166, defines interference as "the effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radio communication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy".

5.2.1.1 Probability of instantaneous interference

Let

A denote "The desired transmitter is transmitting";

B denote "The wanted signal is satisfactorily received in the absence of unwanted energy";

C denote "Another equipment is producing unwanted energy";

D denote "The wanted signal is satisfactorily received in the presence of the unwanted energy".

All of these statements refer to the same small-time period. Then, according to the definitions, interference means "A and B and C and D*", where D* is the negation or opposite of D: Let $P(x)$ denote the "probability of x" and $P(x|y)$ denote the "probability of x, given y". Then, the probability of interference during the small-time period is

$$P(\mathrm{I}) = P(\mathrm{A\ and\ B\ and\ C\ and\ D^*}) \quad (1)$$

It can be shown that this can be expressed in terms of known or computable quantities:

$$P(\mathrm{I}) = [P(\mathrm{B}|\mathrm{A}) - P(\mathrm{D}|\mathrm{A\ and\ C})]\ P(\mathrm{A\ and\ C}) \quad (2)$$

It may be preferable to consider the probability of interference only during the time that the wanted transmitter is transmitting. This probability is:

$$P'(\mathrm{I}) = P(\mathrm{B\ and\ C\ and\ D^*}|\mathrm{A}) \quad (3)$$

which can be reduced to:

$$P'(\mathrm{I}) = [P(\mathrm{B}|\mathrm{A}) - P(\mathrm{D}|\mathrm{A\ and\ C})]\ P(\mathrm{C}|\mathrm{A}) \quad (4)$$

5.2.1.2 Discussion of Equations (2) and (4)

First, consider the difference between Equations (2) and (4). The probability of interference can be interpreted as the fraction of time that interference exists. In Equation (2), this fraction is the number of seconds of interference during a time period divided by the number of seconds the wanted transmitter is transmitting during the time period. This second fraction is larger than the first unless the wanted transmitter is on all the time. $P(\mathrm{B}|\mathrm{A})$ is just the probability that a wanted signal will be correctly received when there is no interference, often expressed as the probability that $S/N \geq R$ where S is the signal power, N is the noise power, and R is the signal-to-noise ratio required for satisfactory service. In some services, this probability is called the reliability, and is often computed when the system is designed. It can

[1] The former CCIR Reports 656, 670, and 829 are no longer available.

be computed if system parameters (for example, transmitter and receiver location, power, required *S*/*N*) are known using statistical data on transmission loss (for example, Recommendation 370 [2)]) and statistical data on radio noise (for example, ITU-R Rec. P.372-6 and Report 670 [3)]).

Many systems, such as satellite or microwave relay point-to-point systems, are designed so that $P(\text{B}|\text{A}) \approx 1$. In other services, such as long-distance ionospheric point-to-point services, or mobile services near the edge of the coverage area, $P(\text{B}|\text{A})$ may be quite small. In this latter case, the probability of interference will not be small regardless of the other probabilities.

$P(\text{D}|\text{A and C})$ is the probability that the wanted signal will be correctly received even when the unwanted energy is present. It can be computed if there is sufficient information about the location, frequency, power, etc. of the source of unwanted energy. For examples, see the references in Report 656 [3)].

Notice that it has been assumed that $P(\text{D}|\text{A and C}) \leq P(\text{B}|\text{A})$; that is, if the signal can be received satisfactorily in the presence of unwanted energy, then it can surely be received satisfactorily in the absence of the unwanted energy. Thus $P(\text{I})$ cannot be negative.

$P(\text{A and C})$ is the probability that the wanted transmitter and the source of unwanted energy are on simultaneously. In some situations, the wanted transmitter and source of unwanted energy may be operated independently. For example, they may be on adjacent channels, or beyond a coordination distance. In this case, $P(\text{A and C}) = P(\text{A})P(\text{C})$, where $P(\text{A})$ is the fraction of time that the wanted transmitter is emitting, and $P(\text{C})$ is the fraction of time that the unwanted source is on.

In other situations, the operation may be highly dependent. For example, the transmitters may be co-channel stations in a disciplined mobile service. In this case $P(\text{A and C})$ is very small, but perhaps not zero, because a station can be located so that it causes interference even when it cannot hear the other transmitter.

The two transmitters might both operate continuously. For example, one might be part of a microwave point-to-point service, and the other a satellite sharing the same frequency band. In this case, $P(\text{A and C}) = 1$, and the probability of interference depends entirely on the factor in square brackets in Equation (2).

Similarly, $P(\text{C}|\text{A}) = P(\text{C})$ if the transmitters operate independently. $P(\text{C}|\text{A})$ is very small if the two transmitters are co-channel stations in a disciplined land mobile service; and $P(\text{C}|\text{A}) = 1$ if the unwanted transmitter is on all the time.

In general, all the terms in Equations (2) and (4) affect the probability of interference, although their relative importance is different in different services.

5.3 Circumstances of interferences

In this part, general criteria are laid down for establishing disturbance limits for the purpose of preventing radio frequency interference (RFI) to happen. In this case, a distinction is made for areas where close coupling exists between noise sources and victim equipment, and for areas with remote coupling.

2) ITU-R Rec. P.370-7, *VHF and UHF propagation curves for the frequency range from 30 to 1000 MHz. Broadcasting Services* was withdrawn in 2001.

3) The former CCIR Reports 656, 670, and 829 are no longer available.

5.3.1 Close coupling and remote coupling

Although an ill-defined borderline exists between areas of close and remote coupling these concepts are generally used in the following terms.

Close coupling refers to a short distance between noise source and receiving antenna (for example, 3 m to 30 m) which is the case for residential sources interfering with broadcasting and land mobile receivers in residential areas. In general, frequencies up to 300 MHz are considered.

Remote coupling refers to longer distances, usually in the range of 30 m to 300 m, which are normal between professional or semi-professional sources and receivers as in the case of individual areas. The relevant frequency spectrum is much broader: 9 kHz to 18 GHz.

For the statements given above, it follows that some similarity exists between close coupling and near-field radiation conditions on the one hand and between remote coupling and far-field radiating conditions on the other hand. However, these concepts do not fully correspond since at frequencies below 1 MHz remote coupling may occur under near-field conditions whereas for frequencies above about 30 MHz close coupling may occur under far-field conditions. In the majority of practical situations, however, the good correspondence between close/remote coupling and near/far-field conditions is useful in evaluation of coupling aspects.

It should be noted that field-strength measurements, which are normally used for evaluating remote coupling characteristics, are actually carried out under near-field conditions in the lower end of the frequency range.

Whereas close and remote coupling are generally used to describe a direct coupling path between noise source and receiving antenna by means of electric, magnetic or radiation fields, an additional coupling mode is conduction coupling. In this case, the noise signal is conducted by the mains network from the mains output of the source to the mains input of the receiver, see also Figure 3, paths a1 and a2. Inside the receiver the noise signal is coupled from the mains port(s) to sensitive circuits of the receiver, as e.g. to its antenna port, or to its IF amplifier circuitry. This must be taken into account when determining the receiver's immunity requirements to injected in-band RF disturbances at its mains port.

Some well-known differences exist between near-field and far-field radiation characteristics, and therefore also for most close and remote coupling cases.

– Under far-field conditions with free-space propagation the relation between electric and magnetic components of the field is fixed and well defined, the relation under near-field conditions is rather undefined, if the source and coupling path characteristics are not known.
– Under far-field conditions the attenuation formula is

$$a = \frac{E_1}{E_2} \mathrm{k} \left(\frac{d_2}{d_1}\right)^x , \qquad \text{or} \qquad a = \frac{H_1}{H_2} \mathrm{k} \left(\frac{d_2}{d_1}\right)^x \tag{5}$$

NOTE The attenuation factor a describes the relation of the field strength E_1 (or H_1) found at distance d_1 to the field strength E_2 (or H_2) found at distance d_2. Factor k may e.g. be interpreted as an additional attenuation factor introduced by a wall allocated between the measurement locations at distances d_1 and d_2.

where

a = attenuation factor;

E_1, H_1 = absolute value of the field strength observed at a location still in the far field, but close to the source;

E_2, H_2 = absolute value of the field strength observed at a location in a more remote distance d_2 than d_1, from the source;

k = correction factor (in the range 1 to 10) counting e.g. for the screening effectiveness of buildings the noise source is allocated in, or for other absorbing obstacles allocated in between the considered locations at the distances d_1 and d_2;

d_1 = small distance in the far field range, but close to the location of the source;

d_2 = measurement distance more remote from the source;

x = propagation coefficient, which is 1 in free-space propagation and somewhat higher (1 to 1,5) for non-free-space propagation.

Under near-field conditions the propagation coefficient x is more complex and dependent on the magnetic or electric component with typical values between 2 and 3.

For this reason, it is much easier to develop a model for remote coupling conditions than for close coupling situations and for conduction coupling paths. Such a model is necessary to derive emission limits for a general interference environment.

5.3.2 Measuring methods

The measuring method is of major importance for specification of a radio frequency disturbance limit. Several measuring methods are applied and a short survey is given in the following paragraphs. In all measurements, the measuring instrument is a selective microvoltmeter (CISPR receiver) as specified for the relevant frequency range.

5.3.2.1 Disturbance voltage/current at mains ports

In the lower frequency range up to about 30 MHz, the mains network may conduct any injected RF energy to nearby users connected to the mains and/or couple part of the RF energy to nearby antennas in the electric, magnetic or radiation mode. Electric or magnetic field coupling to nearby antennas in this frequency range, however, is in most cases of minor importance compared with conduction coupling through the mains network. Because of the RF output voltage conduction mainly coupling through the mains network, the RF output voltage at the mains port is used as a measure for the interfering potential of almost any type of source in this frequency range. This permissible RF output disturbance voltage at the mains port of the source determines the minimum immunity requirements of the victim receiver against injected in-band RF disturbances at the receiver's mains port.

This disturbance voltage at mains ports is measured by means of an artificial mains network which isolates the source from the mains at RF frequency and which furnishes a standardized RF load to the source. For measurement of conducted disturbances, the artificial mains network generally recommended by CISPR is a 50 Ω/50 μH V-network which introduces a parallel impedance of 50 Ω/50 μH between each live or neutral wire of the mains port and reference ground.

Although not recommended by CISPR yet, the asymmetric current in the mains cable, measured by means of a current probe, might be used as a measure for the radiation capability of the source as already specified for telecommunication lines.

Current probe measurements of the asymmetric disturbance current in the mains cable require the mains port to be terminated with a suitable artificial mains network. This network should simulate the typical common mode impedance and RF unbalance (e.g. given as longitudinal conversion loss (LCL)) of the mains network and should decouple incoming common mode disturbances from the mains network side.

5.3.2.2 Disturbance voltage at signal ports

Imperfections of the symmetry in circuits carrying wanted symmetrical signals will produce unwanted asymmetric signals at the related ports and cables connected thereto. In asymmetric (coaxial) ports unwanted external currents can be conducted in the outer surface of the screen because of imperfect screening. These asymmetric signals and external screen currents may couple energy by inductive or radiation fields to nearby or remote antennas.

The asymmetric voltages can be measured by means of an artificial loading network. In this case the use of an asymmetric artificial network (AAN) instead of a V-network is preferred.

5.3.2.3 Disturbance power measurements with the absorbing clamp

The asymmetric RF current in a lead or on the outer surface of the screen of a screened cable will radiate energy to nearby or remote antennas depending on frequency, length and configuration of the connected cable. This is particularly important at VHF and UHF in which frequency ranges the external lead of the appliance has a length which is in the order of a half wavelength or longer.

The absorbing clamp is a device which gives measuring results in a good correspondence with the disturbance power that can be radiated from the external lead of the appliance.

Under this condition the disturbance power conducted through the mains lead and measured by the absorbing clamp is a good measure for the disturbance potential. If the dimensions of the source are not small compared with wavelength, a larger part of the disturbance's energy will be radiated directly and the absorbing clamp measurement is less reliable.

Because broadband disturbance is, in general, of less importance at frequencies above 300 MHz the absorbing clamp is recommended for the measurement of small appliances in the frequency range 30 MHz to 300 MHz.

5.3.2.4 Field-strength measurement

The field strength caused by disturbance sources is likely to be the most straightforward criterion for the interference potential of such a source, because it is more directly comparable with the wanted field strength at the antenna of a radio receiver particularly for remote coupling analysis.

A source radiates RF energy from its case or cabinet if a coupling path exists between internal noise source and external case or cabinet and if the dimensions of the case or cabinet are of the order of one wavelength. For practical reasons the electric component of the field is measured in the frequency range above 30 MHz (by means of dipole antennas) and the magnetic component of the field below 30 MHz (by means of loop antennas).

Field-strength measurements have a number of practical drawbacks. The influence of surrounding reflections should be eliminated which is usually met by using an open area test site (OATS). Such a test site introduces inaccuracies by variable reflections from the operator and from the ground (influence of moisture and season) and by interference from ambient transmitter fields. It also increases the work time due to poor weather and other climatic conditions. These drawbacks can be partly eliminated by use of anechoic rooms in the frequency range above 30 MHz.

Another drawback of field-strength measurements is the complex EUT radiation pattern which also depends on the test set-up. It therefore requires measurements in various directions and an accurately specified test set-up.

5.3.2.5 Radiation substitution measurements

In order to reduce the effect of surrounding reflections in field-strength measurements, the source under test is replaced by a radiator of specified characteristics and an adjustable output level (usually a dipole connected to a calibrated RF generator) to produce the same field strength under equal environmental conditions. The RFI of the appliance is expressed as the equivalent power radiated from the substitution radiator. This method is often used at frequencies above 1 GHz.

5.3.2.6 Disturbance power measurements with a reverberating chamber

The reverberating chamber method in essence is a radiation substitution method inside a screened cage and can be used in the frequency range above 300 MHz. By using rotating reflection plates (mode stirrers), the standing wave patterns inside the cage are continuously varied in such a way that the time averaged field strength is nearly independent of the position inside the cage. Therefore, the source under test and the substitution source need not be at exactly the same position and the calibration procedure for the radiated power is much simpler than in the normal substitution method.

5.3.2.7 Frequency considerations with respect to measuring methods

As indicated earlier, radiation of a device and its connected cables, and particularly of the mains cables, depend on the size of the device and of the cables compared with wavelength (frequency). The following table gives a general survey of the usefulness of various measuring methods with respect to the frequency bands (subdivided according to CISPR Recommendations). It should be noted that the frequency ranges are only for indication and the quoted valuation given for guidance.

Table 2 – Guidance survey of RFI measuring methods

Frequency MHz	Mains & signal port voltage	Asymmetrical current	Absorbing clamp	Field strength	Substitution radiation	Reverberation chamber
0,009 to 0,15	+	+	–	0	–	–
0,15 to 30	+	+	–	0	–	–
30 to 300	–	0	+	+	0	–
300 to 1 000	–	0	0	+	+	0
Above 1 000	–	–	–	+	+	0
Where + = to be recommended; 0 = usable; – = not normally usable.						

5.3.3 Disturbance signal waveforms and associated spectra

An important aspect is the RF spectrum which is associated with the signal waveform. As most radio services use relatively narrow frequency channels, the spectrum (frequency domain) is considered of major importance compared with the waveform (time domain). Therefore the following distinction is made.

Narrowband radio frequency interference (RFI) effects occur when the disturbance signal occupies a bandwidth smaller than the radio channel of interest or the measuring receiver. The disturbance spectrum may consist of a single frequency produced by a sinewave oscillator of medium or high RF power (i.e. by RF ISM equipment) or of low power (i.e. by electronic circuits, receiver oscillators). The oscillator could be modulated by the mains frequency. Oscillator frequencies can be generated over the entire usable frequency spectrum. The effect of narrowband disturbance is considered by CISPR over the frequency range 9 kHz to 18 GHz.

– Narrowband RFI from a disturbance with a rather broadband spectrum of discrete frequencies – Pulse waveforms derived from a digital clock oscillator contain discrete harmonic frequencies in a wide frequency range (broadband spectrum). For fundamental (clock) frequencies appreciably higher than the bandwidth of the radio channel, not more than one separate spectral line can coincide with the radio channel and such a spectral line is considered as narrowband RFI. Clock oscillators of computers are often dithered (i.e. are using frequency modulation on the clock).
– Continuous broadband RFI – Gaussian noise generated by gas discharge devices (lighting) produces continuously a flat spectrum during the operation of the device. Repetitive pulses produce a wide spectrum containing various discrete spectral lines. At repetition rates much lower than the radio channel bandwidth many spectral lines occur within the channel (broadband RFI), originating for example, from pulses derived from the mains frequency (commutator motors, semiconductor-controlled voltage regulators).

  The spectrum amplitude of repetitive pulses decreases above the transition frequency (the reciprocal of the pulse width) at 20 dB or 40 dB per decade, dependent on the pulse shape. Continuous broadband interference (as e.g. from spark ignition noise, arc welding equipment, etc.) is considered by CISPR over the frequency range 150 kHz to 1 GHz or higher.

  Broadband RFI may also be caused by disturbances or wanted signals from RF ISM equipment, as e.g. microwave ovens. There are two main types of microwave ovens depending on the power supply, those with a transformer and those with a switched mode power supply.
– Discontinuous broadband RFI – Switching operations by means of a hard contact (spark) generates short bursts of noise. Short-duration bursts of disturbances may cause less severe interference effects than long-duration bursts depending, however, on the average repetition rate of the bursts.

  For this reason CISPR allows a relaxation with respect to the limit of continuous disturbances for short bursts with a duration of less than 200 ms and with a repetition rate N of less than 30 clicks per minute. This relaxation factor equals 20 log 30/N. The frequency spectrum of such clicks is not essentially different from that of continuous broadband interference.

5.3.4 Characteristics of interfered radio services

The characteristics of radio services with respect to RFI are very important as well. In residential areas, radio services which can suffer from RFI are e.g. radio broadcasting, amateur radio, and (land) mobile radio communication. AM sound broadcasting operates at frequencies below 30 MHz and FM (stereo) sound broadcasting between 64 MHz and 108 MHz. TV broadcasting uses various channels in the range between 50 MHz and 900 MHz, the picture signal being modulated in AM-VSB and the sound signal in either AM or FM depending on the TV standard in use. Broadcasting also takes place in the bands between 11 GHz and 13 GHz. Amateur radio frequency bands are widely spread over the whole RF range and are allocated in the short wave up to the micro wave frequency bands.

Analogue sound and TV broadcasting are going to be replaced by broadcasting with digital modulation, like Digital Radio Mondiale (DRM) which is intended to replace the AM radio in the medium frequency (MF) and high frequency (HF) bands, Digital Audio Broadcasting (DAB or T-DAB) operated in the VHF and UHF bands, and Digital Video Broadcasting Terrestrial (DVB-T) operated in the UHF bands. These digital radio services require lower RF protection ratios (17 dB for DRM, 20 dB for DVB-T and 28 dB for DAB) than radio services with analogue modulation (where RF protection ratios of about 27 dB for AM, about 48 dB for FM and about 58 dB for TV are required). On the other hand, the transition between the interference level defined by the minimum wanted field strength minus the protection ratio and the disturbance which causes unacceptable interference is narrower than for analogue modulation.

In residential areas with private receiving antennas propagation of disturbances by radiation from noise sources and from mains cables is of major importance. Broadcast signals distributed through a cable (CATV) system are less vulnerable because of the more suitable location which can be selected for the common receiving antenna (i.e. for the head station), but if in such cases disturbances are coupled to such an antenna interference may be experienced by all subscribers connected to such a system.

Satellite broadcast signals in the 12 GHz range are generally not disturbed by broadband sources because of the limited frequency spectrum of broadband sources. The risk mainly depends upon the frequencies chosen for the first intermediate frequency band at the receiver.

The annoyance to the broadcast signal depends on the disturbance signal waveform. Narrowband and broadband sources produce different types of annoyance. Subjective tests have shown that for equivalent subjective assessment, narrowband disturbance should be of significantly lower amplitude than broadband disturbance (quasi-peak measured) in the 0,15 MHz to 30 MHz range. Assessment of disturbance to digital radio services is based on the bit-error probability (BEP). Tests have shown that the weighting of impulsive disturbance for its effect on digital radio communication services is generally different from the effect on radio communication services that use analogue modulation.

The influence of the repetition rate of rapid pulses in a broadcast channel is accounted for in the quasi-peak detector characteristic, the effect of low rate pulses (clicks) by the 20 log 30/N relaxation to the limit. In mobile communication (in older systems mainly narrowband FM, now replaced by digital mobile communication systems such as TDMA (e.g. GSM, PDC) and CDMA (e.g. cdmaONE, WCDMA, cdma2000 etc.), traffic noise sources (i.e. ignition interference) are the major source of RFI. In this respect the base station antenna is in a more favourable position with respect to RFI signals than the mobile antenna because of its higher location. Mobile antennas on the other hand change their position continuously and are therefore less vulnerable to stationary noise sources. For the calculation of emission limits in the frequency range above 1 GHz a detector with a weighting function appropriate for digitally modulated radio services may be considered.

Broadcasting and mobile services may be interfered by narrowband sources as well (RF ISM equipment, data processing equipment, receiver oscillators, etc.). The wanted radiated RF power from RF ISM equipment may be several orders higher than the level from broadband sources although the distances between those sources (industrial areas) and the victim receivers are normally longer. The disturbing energy, however, is mainly concentrated in a very narrow frequency band. For this reason a number of frequency bands is reserved for typical ISM applications.

In addition to broadcasting and mobile radio services, many different professional radio services such as fixed, aeronautical navigation, aeronautical mobile, maritime mobile, radiolocation, standard frequency and time, meteorological aids and radio astronomy services are in use. Other professional radio services (navigation, fixed services, satellite and microwave communication) are, in general, less vulnerable to radio interference because of the use of higher frequencies (greater than 1 000 MHz in which broadband interference is negligible), more favourable antenna locations, sophisticated systems (modulation, coding, antenna directivity) and technology (screening, filtering).

5.3.5 Operational aspects

Noise sources in residential areas mainly consist of mass-produced devices for domestic and sometimes for professional use. Such appliances are tested according to statistical procedures which implies that a restricted percentage of p per cent fulfils the limit with a limited confidence q per cent. Small batches reduce the figures p and q and CISPR recommends a value for both p and q of 80 per cent (80% - 80% rule). The rule is in general adequate to protect non-vital radio services like broadcast and most land mobile communication.

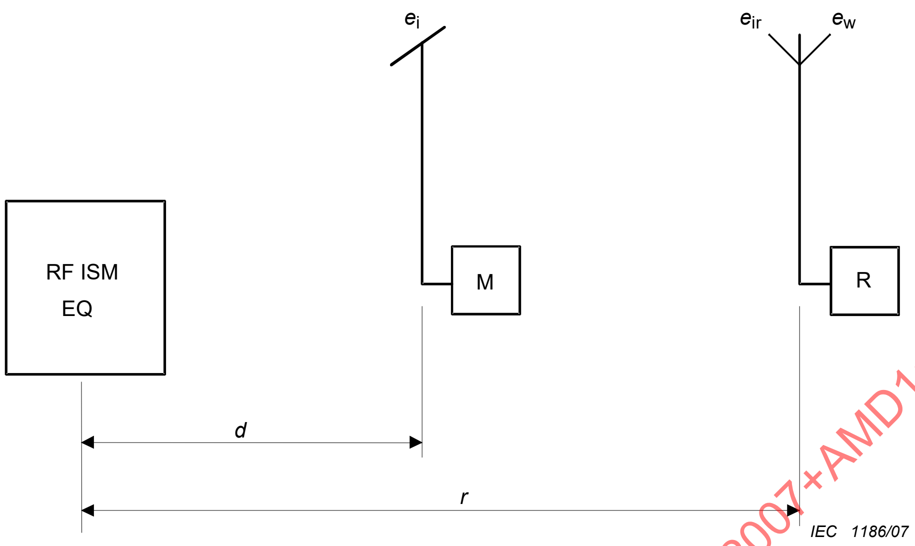
For critical or safety related radio services, however, a much higher degree of confidence is necessary. The actual annoyance in an interfered radio service does not only depend on the RFI field strength, but on the wanted signal level as well. The ratio of wanted-to-unwanted input level which procures a pre-defined and just still permissible minimum quality of performance of the receiver is called RF protection ratio R_p. This way, the wanted signal level needed to get at least the pre-defined minimum quality of performance depends on the natural and man-made noise level and which, in certain environments, may be much higher than the receiver's intrinsic noise level, particularly in the lower part of the radio frequency range.

In establishing limits for various types of noise sources it is important to strive for limits which have an equal effect on the radio services to be protected. The users of such a service are not interested in the type of source which causes RFI. Therefore disturbances from all types of sources should be suppressed as much as possible to an equal level of noise output.

5.3.6 Criteria for the determination of limits

5.3.6.1 Remote coupling

For remote coupling situations the field strength at a specified distance from the noise source is used as a characteristic for the interference potential of the source. The following model (see Figure 2) was developed to derive radiation limits for the case of in-band interference (i.e. interference appearing in the tuned channel of the victim receiver) caused by RF ISM equipment. For the relevant radio services in the allocated frequency bands the RF protection ratio is determined. In ITU documents, this protection ratio is given for disturbing radio services with the same modulation. The protection ratio for any other type of disturbance radiation, as e.g. for typical electromagnetic disturbances from other electrical or electronic apparatus, may be different.



Legend:

$$e_{ir} = e_w / r_p$$

e_{ir} = permissible interference field strength at the position of the antenna of the victim receiver R

e_w = wanted signal field strength to be protected at distance r at the position of the antenna of the victim receiver R (derived from ITU specifications)

r_p = protection ratio, i.e. minimum signal-to-interference ratio needed at the position of the antenna of the victim receiver to guarantee a certain quality of radio reception (derived from ITU specifications)

$$e_i = e_{ir}\ m_{ir}\ l_b\ p\ (r/d)^x$$

e_i = regulated disturbance field strength (CISPR limit) for sources of disturbance, i.e. other electric and electronic equipment and apparatus, at measuring distance d, i.e. at the position of the antenna of the measuring receiver M

m_{ir} = factor for polarization match between polarisation of e_{ir} and polarisation of the antenna of the victim receiver

l_b = screening factor of buildings or other obstacles

p = complex statistical probability factor, for considerations in this sub-clause defined to be 1, generally elaborated in 5.2, and in detail in 5.4. Further on in this report, separate components of this complex probability factor p may be denoted more generally as "influence factors".

x = wave propagation coefficient

NOTE The equations above are only valid for absolute physical quantities.

Figure 2 – Model for remote coupling situation derived disturbance field strength e_{ir} at receiving distance r

Expressed in logarithmic quantities, the permissible interference field strength E_{ir} at the antenna input of the victim receiver is the minimum (or nominal) wanted field strength E_w minus the protection ratio R_p:

$$E_{ir} = E_w - R_p$$

A minimum operational distance r between noise source and receiving antenna is specified and with the use of an estimated or empirical wave propagation factor x, the acceptable disturbance field strength E_i at a specified measuring distance d is calculated:

$$E_i = E_w - R_p + x \cdot 20\ \lg(r/d)$$

Next some additional factors, as e.g. the screening factor of buildings or other obstacles L_b and the factor for polarization match M_{ir}, should be introduced. Furthermore, a statistical factor P on the probability of actual interference under operational conditions should be used to adapt the calculated acceptable disturbance field strength E_i to normal conditions found in practice:

$$E_i = E_w - R_p + M_{ir} + L_b + P + x \cdot 20 \lg(r/d)$$

Such a probability factor P should take into account statistics of antenna directivity (in the direction of the wanted transmitter and of the interference source), distance variations, propagation variations, time coincidence, etc. (see also 5.4).

Adding the screening factor of buildings or other obstacles L_b, the factor for polarization match M_{ir}, and the decoupling attenuation via distance $L_o = x \cdot 20 \lg(r/d)$ into one new term L and setting the statistical probability factor P to 1, we eventually get:

$$E_i = E_w - R_p + L$$

where L actually represents all relaxations in the limits agreeable by CISPR in terms of EMC due to additional decoupling from the victim receiver for disturbances from electric and/or electronic equipment relative to the maximum permissible interference field strength E_{ir} at the antenna input of a victim receiver R, calculable from the radio parameters specified by ITU.

Accomplishing the above calculation by considerations to probability of interference, the final result of this procedure will be a calculated limit which is a good basis for an operational limit guaranteeing that the requirements of the protection ratio R_p are met on a statistical basis (x % of the actual cases). It should be noted that reliable statistical values for most of the parameters mentioned above are still not available to CISPR, and that in those cases rough estimations can be used only.

Moreover the interfering effect of signals in the out-of-band domain is more complex because of the selectivity and non-linearity characteristics of the receiver which can differ from case to case.

5.3.6.2 Close coupling

A simple model for close coupling situations is given in Figure 3. The noise source is considered as an RF generator with an e.m.f. U_s and an internal impedance Z_s for each mains connector/earth combination (for simplicity only one mains connector is shown). The mains network is connected between the noise source and the interfered receiver. The mains network offers a RF impedance Z_m to the source and transfers the energy from the noise source to the mains input port of the receiver.

In addition, part of the conducted RF energy is propagated as a magnetic and electric field. For the close coupling situations generally, near-field conditions exist (ratio electric/magnetic component undefined).

Two coupling paths exist between noise source and receiving antenna:

a) the path of disturbance conducted along the mains network, the mains supply circuit of the receiver and common ground of the receiver's electronic circuitry to the grounding point of the receivers RF input stage, and then via its antenna port input impedance to the antenna itself (path a1), together with the coupling between the mains supply circuit and other RF circuits inside the receiver (path a2). Paths a1 and a2 take effect only in case of mains powered receivers;

b) the path of disturbance conducted along and radiated by the mains network and coupled directly to the external or built-in antenna of the receiver. Path b exists for both, AC mains and battery powered receivers.

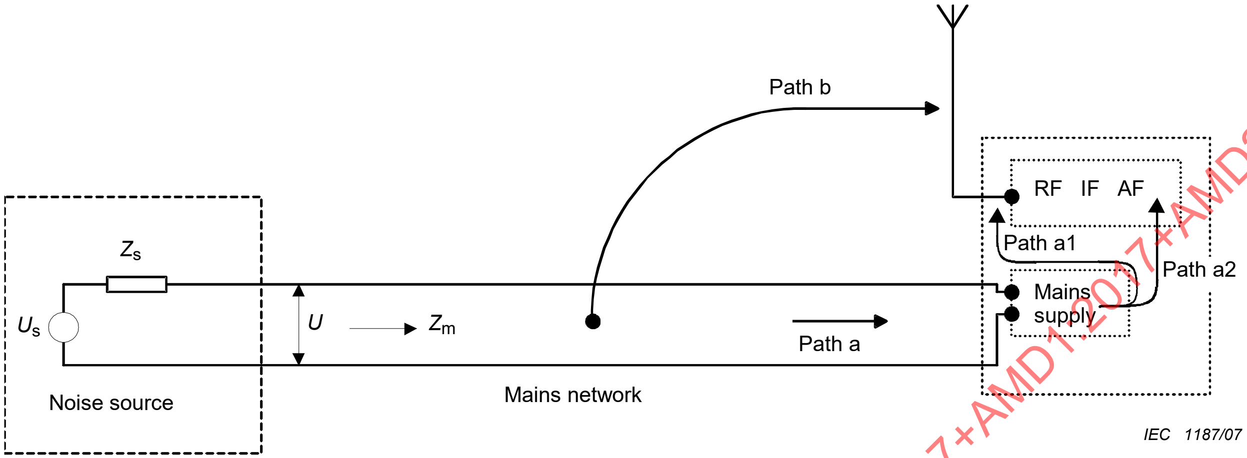


Figure 3 – Model for close coupling situations

In the case of external antennas, the RF power coupled through external path b) exceeds the power via path a1 and a2 appreciably. Moreover the internal coupling via a2 is determined by the mains immunity characteristics of the receiver, i.e. by the screening effectiveness of the internal IF and AF circuitry of the receiver, and it has been shown that it is not difficult to control the mains immunity factor of a receiver to an adequate level. This is however not the case for path a1 since the coupling always happens at the antenna port via the RF input impedance of the receiver's RF input stage. Therefore the attention is mainly focused on path b and path a1). Due to so far lacking investigation, for internal ferrite antennas no clear distinction can be made between paths a) and b). For build-in rod-antennas (used in the frequency range 1,7 to 30 MHz) clear distinction can be made between path a1 and path b. For calculation of CISPR limits in frequency bands up to 30 MHz used for AM radio broadcasting, it should be taken into account that ITU-R Rec. BS.703 specifies a receiver with built-in antennas (ferrite or telescopic rod antennas, depending on frequency range) as the reference receiver.

The modelling starts the same way as in the case of remote coupling. The acceptable disturbance field strength at the receiving antenna is calculated from the RF protection ratio and field strength to be protected in the relevant frequency bands. In the next step the coupling factor is measured from mains input (RF-voltage) to field strength at the antenna. It is, however, more usual to define a transfer factor as the ratio of the RF-voltage injected into the mains and the antenna output voltage (for a specified antenna). This factor is known as the mains decoupling factor. Because of the wide spread in actual situations, extensive statistical material is needed to found a basis for disturbance limits derived from mains decoupling factors. CISPR Report No. 31 ("Values of mains decoupling factor in the range 0,1 MHz to 200 MHz", see Annex A) shows median values, standard deviations and minimum values of the mains decoupling factor. The effect of coupling path a) is described in 5.5.2.1, whereas the effect of coupling path b) for mains and telecommunication line coupling is described in 5.5.2.2.

Another statistical aspect in the calculation of limits in this concept is the variation of the RF-impedance at the mains input. Although individual decoupling factors are determined by the measured voltage, independent of the actual mains impedance, the interference limit shall be defined for a fixed simulated impedance (artificial mains network impedance), in order to get reproducible measuring results during CISPR disturbance measurements at standardized test sites. In practice, the RF-load impedance of the mains network varies from location to location and from time to time. This aspect should be considered in deriving a limit from mains decoupling measuring data.

In general, close coupling of an appliance connected to the mains can sufficiently be evaluated by measurement of the disturbance voltage at its mains port. For a given mains network, only one unique set of limits for conducted emissions at the mains port of connected appliances should be used. As a consequence, the stricter limit should apply, if for the mains port two different limits result from the limit calculation for paths a) and b), respectively.

5.3.6.3 General

The derivation of limits from a hypothetical model requires the introduction of various experimental data in such a model. As these data, as pointed out earlier, are based on statistical measurements under different actual circumstances, the usefulness of such data for general application is often debatable.

On the other hand, the implementation of suppression measures should be considered on physical, operational, manufacturing and not in the least on economic aspects. Therefore the model should be used as a worthwhile starting point but the final limit value is often the result of an agreement between parties involved after extensive considerations and negotiations.

5.4 A mathematical basis for the calculation of CISPR limits

This subclause contains the basic mathematical model that can be used for calculation of CISPR limits. The start-up point is the supposition that there is an identifiable probability inequality to be satisfied, and the assumption that the parameters obey a log-normal distribution.

5.4.1 Generation of EM disturbances (source of disturbance)

From the mathematical point of view any limit must be calculated with the provision that the inequality

$$z = x/y \geq 1 \tag{6}$$

is satisfied with some probability α.

If in Equation (6) x and y are independent random values of quantities (e.g. of disturbance signals, immunity, etc., which influence the radio reception quality) with log-normal distribution, then $10\lg(x) = X$ (dB) and $10\lg(y) = Y$ (dB) will have normal distribution with parameters μ_x (dB), μ_y (dB), σ_x (dB) and σ_y (dB). Hence $X - Y = Z$ (dB) will have a normal distribution with the parameters

$$\mu_Z = \mu_x - \mu_y \qquad \text{and} \qquad \sigma_Z = \left[\sigma_x^2 + \sigma_y^2\right]^{1/2}$$

In this case

$$P\left(\frac{x}{y} \geq 1\right) = P\left(Z \geq 0\right) = P\left(\frac{Z - \mu_Z}{\sigma_Z} \geq \frac{-\mu_Z}{\sigma_Z}\right) = P\left(\frac{Z - \mu_Z}{\sigma_Z} \leq \frac{\mu_Z}{\sigma_Z}\right) = F\left(\frac{\mu_Z}{\sigma_Z}\right) \tag{7}$$

where F denotes the normal $N(0,1)$ distribution function (see [1][4]).

The reliability of obtaining a pre-set level α for the quality of a radio service is expressed by:

$$\alpha = P\left(\frac{x}{y} \geq 1\right), \qquad \text{therefore:} \qquad \frac{\mu_Z}{\sigma_Z} = F^{-1}(\alpha) = t_\alpha \tag{7a}$$

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

where t_α is the α-quantile of the centralized normal distribution (see [1], page 180).

Solving Equation (7a) relative to μ_x or μ_y, we get:

$$\mu_x = \mu_y + t_\alpha \sigma_z \quad (8)$$

$$\mu_y = \mu_x - t_\alpha \sigma_z \quad (9)$$

The CISPR limit L is determined for some quantile t_β in distribution of probabilities of the value x or y for which limits are established, in such a way that the following equalities are true:

$$\beta = P(X \geq L_X) \quad \text{i.e.} \quad L_x = \mu_x - t_\beta \sigma_x \quad (10)$$

$$\beta = P(Y \leq L_Y) \quad \text{i.e.} \quad L_y = \mu_y + t_\beta \sigma_y \quad (11)$$

where t_β is the β-quantile of the centralized normal distribution (see [2], page 84 example 2.17).

Substituting Equation (8) into Equation (10) and Equation (9) into Equation (11)

$$L_x = \mu_y + t_\alpha \sigma_z - t_\beta \sigma_x \quad (12)$$

$$L_y = \mu_x - t_\alpha \sigma_z + t_\beta \sigma_y \quad (13)$$

one is enabled to calculate limits for different parameters, which ascertain the radio reception quality.

5.4.2 Immunity from EM disturbances (victim receiver)

Inequality (6) has the form:

$$x/y \geq 1$$

where

x is a parameter of receptor immunity;

y is a parameter of electromagnetic environment in respect to which the immunity limit is established.

If the values X (dB) and Y (dB) are satisfactorily approximated by normal distributions with parameters μ_x, σ_x, μ_y, σ_y then

$$\sigma_z = \left[\sigma_x^2 + \sigma_y^2\right]^{1/2} \quad (14)$$

In this case, according to Equation (12), the equation for the calculation of receptor immunity limits has the following form:

$$L_x = \mu_y + t_\alpha \left[\sigma_x^2 + \sigma_y^2\right]^{1/2} - t_\beta \sigma_x \quad (15)$$

5.5 Application of the mathematical basis

5.5.1 Radiation coupling

NOTE This describes the effect of remote coupling as in 5.3.6.1.

This subclause adapts the basic model for the case where it is wished to protect a radio service when there is radiation coupling from the source of EM disturbance to the antenna of the radio receiver. The actual signal-to-disturbance ratio R can be expressed in terms of the wanted signal, the disturbing signal, the propagation losses and the antenna gain, as follows:

$$R = E_w(\mu_w;\sigma_w) + G_w(\mu_{Gw};\sigma_{Gw})$$

$$- [E_i(\mu_i;\sigma_i) + G_i(\mu_{Gi};\sigma_{Gi}) - L_o(\mu_{Lo};\sigma_{Lo}) - L_b(\mu_{Lb};\sigma_{Lb}) + M_{ir}(\mu_m;\sigma_m)] \quad \text{dB} \tag{16}$$

where

E_w is the actual field strength of the wanted signal at the position of the radio receiver's antenna as a function of its mean value (μ_w) and the standard deviation (σ_w);

E_i is the field strength of the disturbance signal at the measurement distance d on a test site as a function of its mean value (μ_i) and standard deviation (σ_i);

G_w is the actual value of the radio receiver's antenna gain for the wanted signal as a function of its mean value (μ_{Gw}) and standard deviation (σ_{Gw});

G_i is the actual value of the radio receiver's antenna gain for the disturbance signal as a function of its mean value (μ_{Gi}) and standard deviation (σ_{Gi});

L_o is the actual value of the factor which takes account of the attenuation of the disturbance field strength on its propagation path to the position of the radio receiver's antenna when it is propagated through free space without obstacles as a function of its mean value (μ_{Lo}) and standard deviation (σ_{Lo}) in relation to the measurement distance d on the test site:

$$L_o = x \cdot 20 \lg(r/d);$$

L_b is the actual value of the factor which takes account of the attenuation of the disturbance field strength caused by obstacles in its propagation path as a function of its mean value (μ_{Lb}) and standard deviation (σ_{Lb}) relative to the value for free-space propagation.

M_{ir} is the actual value of the factor for polarization match between the disturbance field strength E_{ir} and the receiving antenna of the victim receiver as a function of its mean value (μ_m) and standard deviation (σ_m). The absolute value m_{ir} equals 1, when the receiving antenna polarization matches the polarization of E_{ir} and becomes less than 1 in all other cases. Since M_{ir} and the related mean value μ_m are used in logarithmic terms their quantities are equal to or smaller than 0 dB and thus always have a negative sign.

If, as assumed, all variables on the right-hand side of Equation (16) obey a normal distribution law, then the distribution factors are related as follows:

$$\mu_R = \mu_w + \mu_{Gw} - \mu_i - \mu_{Gi} + \mu_{Lo} + \mu_{Lb} - \mu_m \quad \text{dB} \tag{17}$$

$$\sigma_R^2 = \sigma_w^2 + \sigma_{Gw}^2 + \sigma_i^2 + \sigma_{Gi}^2 + \sigma_{Lo}^2 + \sigma_{Lb}^2 + \sigma_m^2 \quad (\text{dB})^2 \tag{18}$$

With a normal distribution law the reliability of obtaining the pre-set quality of service can be expressed by the following function of the normal probability distribution:

$$P(R > R_p) = F[-(R_p - \mu_R) / \sigma_R] = \alpha \tag{19}$$

therefore:

$$\mu_R = R_p + t_\alpha \sigma_R \tag{20}$$

where $t_\alpha = F^{-1}(\alpha)$

By combining Equations (17), (18) and (20) an expression is obtained for the permissible mean value (μ_i) of the disturbance field strength at a pre-set distance from the source of disturbance:

$$\mu_i = \mu_w + \mu_{Gw} - \mu_{Gi} + \mu_{Lo} + \mu_{Lb} - \mu_m - R_p$$
$$- t_\alpha \left[\sigma_w^2 + \sigma_{Gw}^2 + \sigma_i^2 + \sigma_{Gi}^2 + \sigma_{Lo}^2 + \sigma_{Lb}^2 + \sigma_m^2 \right]^{1/2} \quad (21)$$

The mean value of the disturbance shall be below the limit, and may be specified as follows:

$$\beta = P(E_i \le E_{Limit}) \qquad \text{i.e.} \qquad E_{Limit} = \mu_i + t_\beta \sigma_i \quad (22)$$

where

E_{Limit} is the limit for the disturbance measured on a test site at a specified distance; and

t_β is the β-quantile of the centralized distribution function which corresponds to a probability level of compliance with the limits.

The free space attenuation factor (μ_{Lo}) can be evaluated from

$$\mu_{Lo} = x \cdot 20 \lg (r/d) \quad (23)$$

where

r is an average distance between the disturbance source and the receiving antenna;

d is the pre-set or specified measurement distance on the test site;

x is the exponent which determines the actual free-space attenuation rate.

Combining Equations (21), (22) and (23) the limit is given by:

$$E_{Limit} = \mu_w + \mu_{Gw} - \mu_{Gi} + x \cdot 20 \lg (r/d) + \mu_{Lb} - \mu_m - R_p + t_\beta \sigma_i$$
$$- t_\alpha \left[\sigma_w^2 + \sigma_{Gw}^2 + \sigma_i^2 + \sigma_{Gi}^2 + \sigma_{Lo}^2 + \sigma_{Lb}^2 + \sigma_m^2 \right]^{1/2} \quad (24)$$

CISPR Recommendation 46/1 (see CISPR 16-4-3) specifies that 80 % of series-produced equipment should meet the disturbance limit, and that the testing should be such that there is 80 % confidence that this is so. For these conditions t_β assumes a value of 0,84.

5.5.2 Wire-line coupling

5.5.2.1 Mains coupling using the mains decoupling factor

NOTE This describes the effect of coupling path a) as in 5.3.6.2.

The required quality of radio communications is considered to be fulfilled, if the probability, that the actual signal-to-disturbance ratio R is greater than the minimum acceptable value R_p, exceeds a specified value. That is

$$P(R > R_p) \ge \alpha \quad (25)$$

where

R is the actual signal-to-disturbance ratio at the receiver's antenna port;

R_p is the minimum acceptable value of the signal-to-disturbance ratio at the receiver's antenna port;

α is a specified value representing the reliability of radio communications.

The relationship between the actual signal-to-disturbance ratio and generated electromagnetic disturbance is:

$$R = U_w - U_{ir = Uw} - U_i + K \quad \text{dB} \tag{26}$$

where

U_w is an effective value of wanted signal at the receiver's antenna port or feeding point;

U_{ir} is the permissible effective disturbance level at the receiver's antenna port or feeding point;

U_i is a value of a specified component of the electromagnetic disturbance (as e.g. voltage, current, power, etc.) measured at the mains port of the disturbance source in a specified way using specified equipment (i.e. a quasi-peak detector);

K is a decoupling factor defined as a ratio of U_i to an effective value of electromagnetic disturbance signal U_{ir} at the receiver's antenna port or feeding point.

For the situations where the disturbance is coupled predominantly by conduction (frequencies below 30 MHz):

$$K = K_m + I \quad \text{dB} \tag{27}$$

where

K_m is the mains decoupling factor relating U_i measured at the source (by an artificial mains network) to the value of disturbance at the mains input to the receiving installation;

I is the mains immunity factor relating the value of disturbance at the mains input to an equivalent disturbance which, if applied at the antenna port or feeding point of the receiving installation, would produce the same effect.

NOTE Such a receiving installation may comprise a usual broadcast radio receiver with built-in antenna, or a professional radio receiver connected to an external outdoor antenna as well.

It has been established experimentally that probability distributions of U_w (dB), U_i (dB) and K for arbitrarily selected disturbance sources, radio receiving installations and distances between them is well approximated by a normal distribution law.

A limit for electromagnetic disturbances applying to the mains port of the disturbance source is established for a definite quantile $U_i(p)$ in the probability distribution of U_i. A permissible value L for $U_i(p)$ is selected in such a way that at $U_i(p) = L$, a reliability of guaranteeing a radio reception which has a quality $R \geq R_p$ would be equal to the specified value α:

$$U_{Limit} = L_{pr}(U_i) = \mu_{Uw} + \mu_k - R_p + t_\beta \sigma_{Ui} - t_\alpha [\sigma^2_{U_w} + \sigma^2_{U_i} + \sigma^2_k]^{1/2} \tag{28}$$

μ and σ^2 are expectations/variances of corresponding components; $t_\alpha = F^{-1}(\alpha)$, $t_\beta = F^{-1}(ß)$ are arguments of a standard normal distribution function (with zero mean and variance of unity) which is equal to t_α and t_β, respectively.

For series-produced articles CISPR recommends that $ß = 0{,}8$; then $t_\beta = 0{,}84$. A value of α is selected between 0,8 and 0,99, depending on the type of a radio network (radio broadcasting, air navigation, *et al*). When $\alpha = 0{,}95$, then $t_\alpha = 1{,}64$.

It has been found experimentally that σ_k is the most significant factor. A change in the value of σ_k with an equivalent change in the limit for U_i results in no variation from the specified quality and reliability of radio performance. Therefore, limits are calculated for equipment located in similar conditions relative to radio receiving installations of a given radio network. For instance, in order to protect a broadcast reception in dwelling houses, it is enough to consider two groups only:

– equipment located in dwelling houses or connected to their supply mains;
– equipment located outside dwelling houses.

The second group, on the basis of economic considerations and separation distance, is divided into the following subgroups: power lines; electric transport; motor vehicles; industrial equipment located in an assigned territory; etc.

5.5.2.2 Mains and telecommunication line coupling by radiation from a network

NOTE This describes the effect of coupling path b) described in 5.3.6.2

This model assumes:

– the injection of symmetric (differential mode), asymmetric (common mode) and combinations thereof (i.e. unsymmetrical) voltages/currents into the network and the conversion of symmetric and symmetric components of unsymmetrical voltages/currents into effective asymmetric (common mode) voltages/currents due to the properties of the complete installation (network including connected apparatus);
– the attenuation of asymmetric disturbances between source and victim receiver location along the distribution network
– the generation of a magnetic (near-)field by asymmetric (common mode) disturbance currents and the coupling of this field into ferrite antennas of broadcast radio receivers in the long and medium frequency ranges,
– the generation of an electric (near-)field by asymmetric (common mode) disturbance voltages and the coupling of this field into telescopic rod antennas of radio receivers in the higher frequency range, and
– in the frequency range above about 10 MHz the generation of an electromagnetic field by the asymmetric (common mode) disturbance power via a radiating half-wave dipole and the coupling of this field into the antenna of radio receivers operating in this frequency range.

Similar to 5.5.1 we define the following quantities (with log-normal distribution):

E_w is the actual field strength of the wanted signal at the position of the radio receiver's antenna as a function of its mean value (μ_w) and standard deviation (σ_w);

E_{ir} is the actual field strength of the disturbance signal (generated by the asymmetric disturbance current $I_{i,}$ on a cable of the network ($E_{ir} = Z_0\ H_{ir}$), or generated by the asymmetric disturbance voltage $U_{i,}$ or generated by the asymmetric disturbance power P_i) at the position of the receiving antenna as a function of its mean value (μ_i) and standard deviation (σ_i);

M_{ir} is the actual value of the factor for polarization match between the disturbance field strength E_{ir} and the receiving antenna of the victim receiver as a function of its mean value (μ_m) and standard deviation (σ_m). The absolute value m_{ir} equals 1, when the receiving antenna polarization matches the polarization of E_{ir} and becomes less than 1 in all other cases. Since M_{ir} and the related mean value μ_m are used in logarithmic terms their quantities are equal to or smaller than 0 dB and thus always have a negative sign.

C is the value of the conversion factor $C_I = E_{ir}/I_i$ or $C_U = E_{ir}/U_i$ or $C_P = E_{ir}/P_i$ as a function of its mean value (μ_c) and standard deviation (σ_c). C_I and C_U can be estimated, in a first approach, by use of the law of Biot-Savart, if for that estimation the impedance Z at the point of interest is taken into account, and C_P can be estimated by the field strength expected from a tuned half-wave dipole substituting a certain cable length at the given location. Since C is always smaller than 1, its logarithmic quantities become negative;

A is the value of the attenuation between I_i' (resp. U_i' or P_i') at the source location and I_i (or U_i, or P_i, respectively) at the receiver location as a function of its mean value (μ_a) and standard deviation (σ_a);

Z is the value of the (frequency-dependant) impedance between the effective asymmetric disturbance voltage U_i and the effective asymmetric disturbance current I_i at the same (e.g. source) location as a function of its mean value (μ_z) and standard deviation (σ_z);

U_i' is the value of the effective asymmetric voltage at the source location as function of its mean value (μ_u) and standard deviation (σ_u);

P_i is determined by the ratio of U_i^2/Z or $I_i^2 \cdot Z$ at the points of interest;

Then (written as logarithmic quantities) the actual signal-to-disturbance ratio R is

$$R = E_w\,(\mu_w;\sigma_w) - [E_{ir}(\mu_{ir};\sigma_{ir}) + M_{ir}(\mu_m;\sigma_m)] \quad (29)$$

with

$$E_{ir}\,(\mu_{ir};\sigma_{ir}) = U_i'\,(\mu_u;\sigma_u) - Z(\mu_z;\sigma_z) - A(\mu_a;\sigma_a) + C(\mu_c;\sigma_c) \quad (30)$$

and the permissible mean value of the disturbance field strength will be obtained using:

$$\mu_{ir} = \mu_w - \mu_m - R_p - t_\alpha(\sigma_w^2 + \sigma_m^2 + \sigma_{ir}^2)^{1/2} \quad (31)$$

μ_{ir} can also be expressed as μ_{ir}/dB(μV/m) = μ_u/dB(μV) – μ_z/dB(Ω) – μ_a/dB + μ_c/dB(Ω/m), and σ_{ir} can be expressed as $\sigma_{ir}^2 = \sigma_u^2 + \sigma_z^2 + \sigma_a^2 + \sigma_c^2$ (units of σ in dB).

Therefore the permissible mean value of the asymmetrical (common mode) disturbance voltage can be defined as

$$\mu_u = \mu_w - \mu_m - R_p + \mu_z + \mu_a - \mu_c - t_\alpha(\sigma_w^2 + \sigma_m^2 + \sigma_u^2 + \sigma_z^2 + \sigma_a^2 + \sigma_c^2)^{1/2} \quad (32)$$

Taking into account Equation (22), the limit U_{Limit} becomes

$$U_{Limit} = \mu_w - \mu_m - R_p + \mu_z + \mu_a - \mu_c + t_\beta\sigma_u - t_\alpha(\sigma_w^2 + \sigma_m^2 + \sigma_u^2 + \sigma_z^2 + \sigma_a^2 + \sigma_c^2)^{1/2} \quad (32a)$$

Respectively, in the frequency range above 10 MHz, the disturbance field strength can be estimated by

$$E_{ir} = 7/d \cdot \sqrt{P_i} \quad (33)$$

That means that

$$\mu_{ir}/\text{dB}(\mu\text{V/m}) = 20\,\lg(7/d)/\text{dB}(\Omega^{½}/\text{m}) + \mu_u/\text{dB}(\mu\text{V}) - 0{,}5\mu_z/\text{dB}(\Omega^{½}) - \mu_a/\text{dB}$$

For d = 3 m, the first term is 7,4 dB

$$\mu_u = (\mu_w - \mu_m - R_p + \mu_a + 0{,}5\mu_z - 7{,}4) - t_\alpha(\sigma_w^2 + \sigma_m^2 + \sigma_u^2 + \sigma_z^2/4 + \sigma_a^2)^{1/2} \quad (34)$$

Taking into account Equation (22), the limit U_{Limit} becomes

$$U_{Limit} = (\mu_w - \mu_m - R_p + \mu_a + 0,5\mu_z - 7,4) + t_\beta\sigma_u - t_\alpha(\sigma_w{}^2 + \sigma_m{}^2 + \sigma_u{}^2 + \sigma_z{}^2/4 + \sigma_a{}^2)^{1/2} \quad (34a)$$

Example for the AM frequency range:

According to ITU Recommendation BS.703, the minimum receive field strength μ_w (σ_w set to 0) should be

- for Band 5 (LF): 66 dB(μV/m)
- for Band 6 (MF): 60 dB(μV/m)
- for Band 7 (HF): 40 dB(μV/m) (for DSB and SSB modulation)

whereas the other mean values have been assumed as

- RF protection ratio: R_p = 27 dB
- Polarization match: μ_m = – 6 dB, and σ_m = 4 dB
- Impedance: μ_z = 34 dB(Ω) (i.e. Z = 50 Ω), and σ_z = 4 dB
- Attenuation: μ_a = 10 dB, σ_a = 5 dB
- Conversion factor: μ_c = – 27 dB(Ω/m), if the receiver is assumed to operate at a distance of 3 m from a cable of the network, with σ_c = 3 dB.
- Standard deviation of the disturbance voltage: σ_u = 15 dB (see Figure 4 below)

Applying Equation (32a) to the MF range, with t_α = 0,84 and t_β = 0,84, the permissible mean value of the asymmetric disturbance voltage becomes 41,67 dB(μV) and the calculated limit becomes 54,27 dB(μV).

Using Equation (34a) for the range at 30 MHz we get the permissible disturbance mean voltage as 15,1 dB(μV) and the calculated limit becomes 27,7 dB(μV). This value is calculated under the assumption of far field conditions.

Guidance for field-strength measurements:

In the long and medium wave frequency bands, the disturbance field strength should be measured with a loop antenna, whereas in the short wave frequency bands, the disturbance field strength should be measured with a highly balanced shortened dipole antenna (it is not possible to use rod antennas in buildings since the counterpoise is floating).

Example of a measurement result:

It is normally not possible to model complicated network structures, like e.g. AC mains networks. It is therefore necessary to make a sufficient number of measurements with subsequent statistical evaluation of the results. For that purpose it is advisable to feed a certain (common or differential mode) power into the network and to measure the maxima of the magnetic (or electric) field strength at defined distances from the feed point along the network and at certain distances (e.g. 3 m, which may be difficult inside buildings) from the network lines, at a number of points which is sufficient for the determination of valid statistical parameters.

The measurement results presented in Figure 4 have been obtained in a study executed in Dresden commissioned by the German administration, see [3].

All data for the conversion factor were obtained by measuring the magnetic component of the disturbance field strength H_k in a building with 4 feed points using 26 different field-strength measurement locations. For the standard deviation s(H_k), the right hand scale of Figure 4 applies.

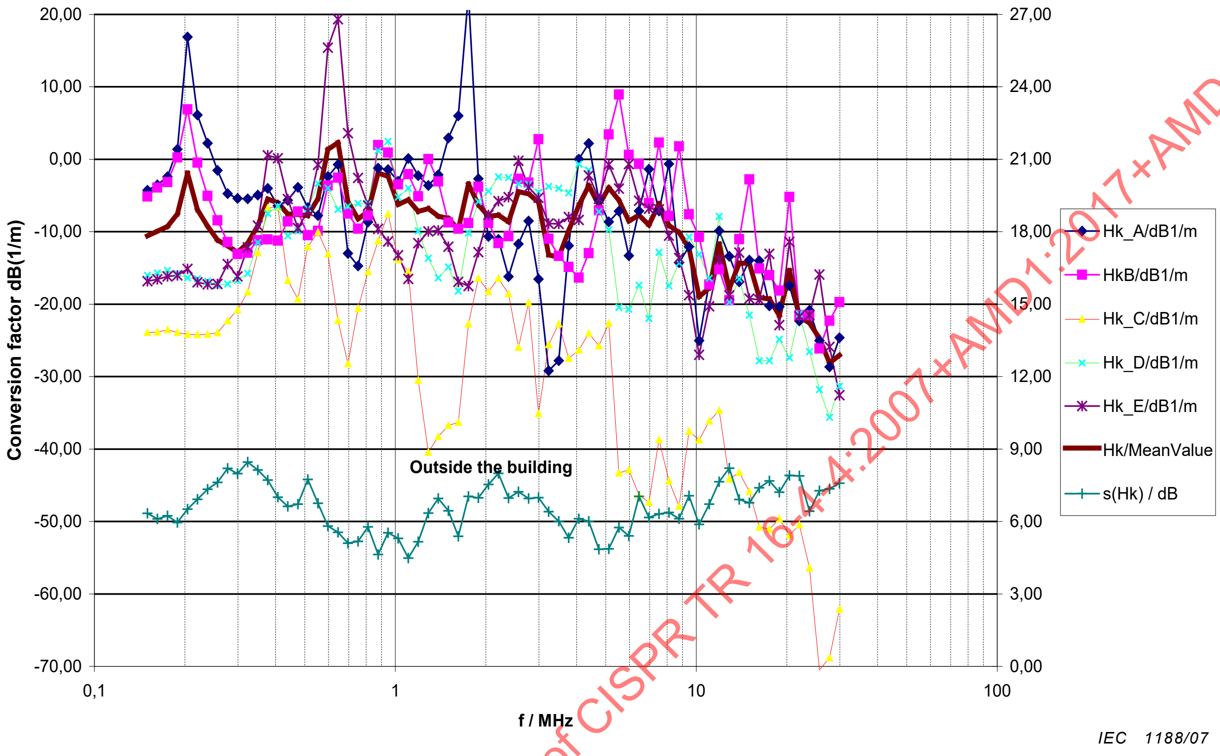


Figure 4 – Example of conversion factors – field strength / common-mode voltage (in dB) – at feed point, found in practice

The conversion factor (field strength divided by common-mode voltage, in dB) helps to determine limits for the common-mode voltage for a given scenario (with e.g. the radio service operated at a certain distance from the network, and assuming a specified longitudinal conversion loss (LCL) for the network).

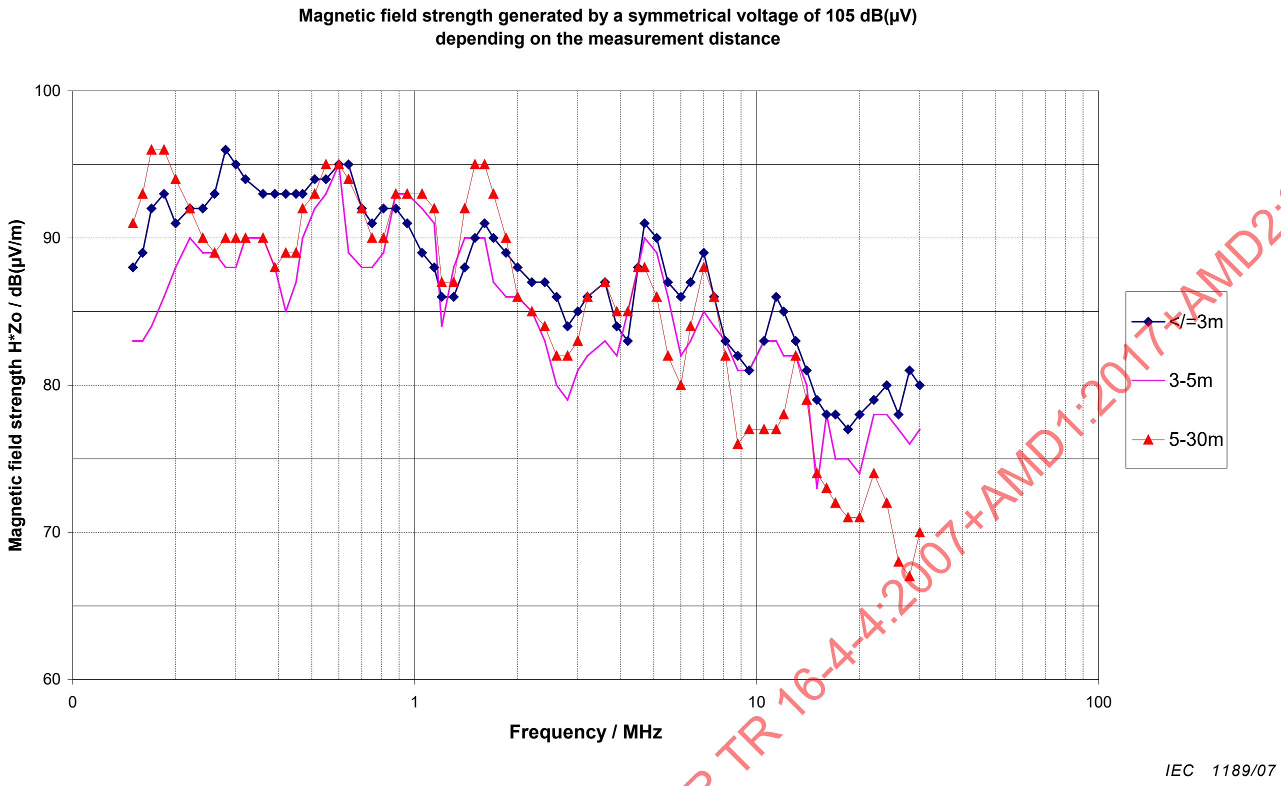


Figure 5 – Example of conversion factors – field strength generated by differential-mode voltage – at feed point, found in practice

Other conversion factors have been obtained feeding a certain differential-mode power into power-line networks (see Figure 5). The comparison of the conversion factors for differential and for common-mode power will show the effective differential mode rejection of the network.

Figure 5 shows an example of results from measurements of the magnetic disturbance field strength (H-field converted to E-field using the free-space wave propagation impedance Z_0) generated by a differential-mode voltage injected into a LV AC mains network between life and neutral lines. From this measurement result, the conversion factor from differential-mode voltage to field strength can be obtained. (The example indicates the 90% value of the field strength, i.e. the field strength not exceeded by 90% of the values. The results base on 48 measurement points within a distance of up to 3 m, 57 measurement points between 3 and 5 m and 87 measurement points between 5 and 30 m.)

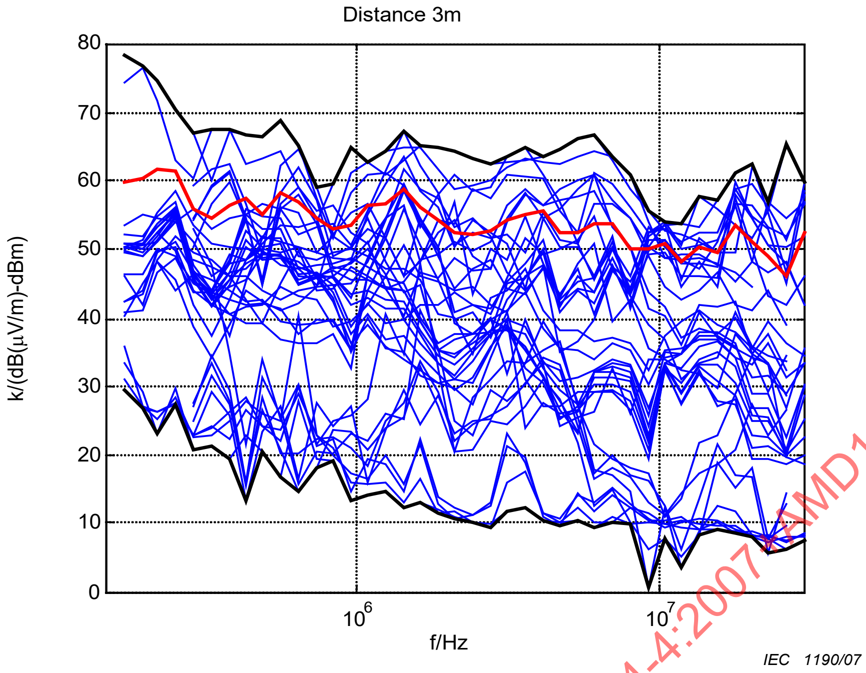


Figure 6 – Example of conversion factors – field strength generated by differential-mode voltage – outside buildings and electrical substations, found in practice

Figure 6 shows an example of results of measurements of the magnetic disturbance field strength (H-field converted to E-field using the free-space wave propagation impedance Z_0) generated by a differential-mode voltage of 108 dBµV (9 kHz) injected into a three phase LV AC mains network between two phase lines. The red line indicates the 80% field strength, i.e. at least 80% of all measurement results are lower than the red line value, with a confidence of 80%. The results base on measurements at 160 points within a distance of 3 m from buildings and electricity substations. Notice that this is not always identical with the distance to the cables of the mains grid.

Figure 7 shows an example of results of measurements of the magnetic disturbance field strength (H-field converted to E-field using the free-space wave propagation impedance Z_0) generated by a differential-mode voltage of 108 dBµV (9 kHz) injected into a LV AC mains network between phase and neutral lines. The red line indicates the 80% field strength, i.e. at least 80% of all measurement results are lower than the red line value, with a confidence of 80%. The results base on measurements on 67 points within a distance of up to 3 m from the cables in the middle of normal rooms inside buildings.

NOTE Figures 6 and 7 show the coupling factor *k* as a function of frequency. It is defined as the transfer function between the forward power injected into the LV AC mains network and the produced field strength. Using *k*, the upper limit value of the wanted signal power may be determined which may be injected into a telecommunication network without exceeding a given disturbance limit.

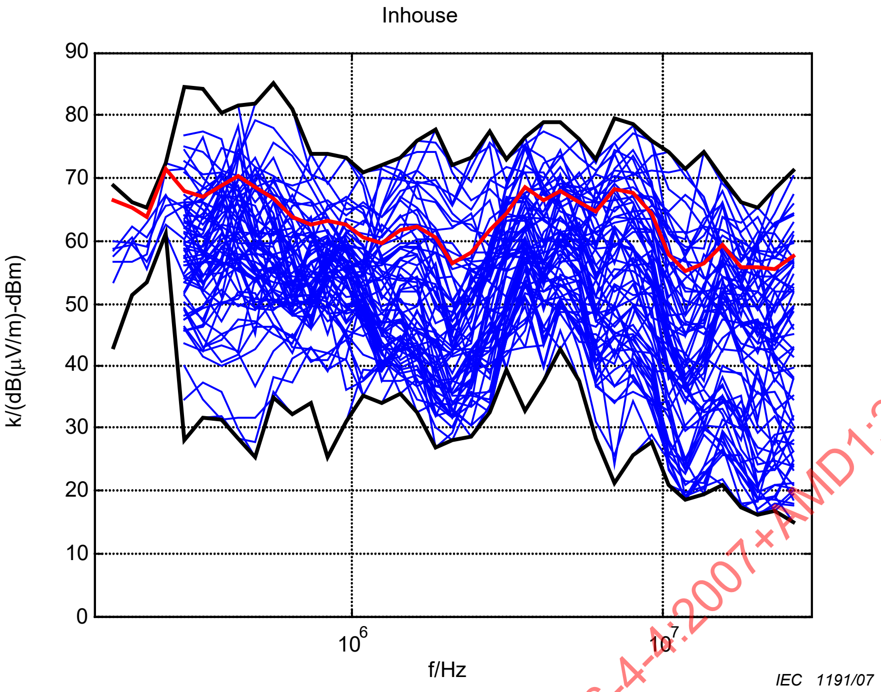


Figure 7 – Example of conversion factors – field strength generated by differential-mode voltage – inside buildings, found in practice

5.6 Another suitable method for equipment in the frequency range 150 kHz to 1 GHz

5.6.1 Introduction

The purpose of this subclause is to review studies made for the derivation of CISPR limits for the protection of telecommunications from interference from RF ISM equipment and to conclude from these a recommended method which meets the objectives of CISPR and ITU. The model deals only with radiation which occurs outside the wanted frequency bands designated by ITU for use by industrial, scientific, and medical (ISM) applications, i.e. outside the ISM bands.

5.6.2 Derivation of limits

The full range of parameters to be taken into account in the derivation of limits is shown in Table 3 together with the major radio services requiring protection.

5.6.2.1 Protection of communication services

The wanted field strength to be protected, the protection ratio required for the different types of radio services, the distance from the source at which protection is necessary, and the attenuation law to be used in the calculation are important. These are matters in which ITU support is essential.

5.6.2.2 Proposed model for use in calculating disturbance limits

The factors that have traditionally been included in models for predicting interference from radio-frequency sources are listed in columns 1 to 10 of Table 3. By assigning appropriate values to each parameter, for example, field strength to be protected, protection ratio, etc., worst-case limits for protecting the various communication services from interference from a certain type of equipment may be determined. However, a model which is based on worst-case parameters is both technically and economically unrealistic since it ignores the fact that there have been very few instances of interference attributed to the distinct type of equipment actually considered. It is therefore critical that the experience in this subject should be taken into account. Thus, the benefits of worldwide experience in this subject can be included although it is recognized that the probability can only be a qualified estimate at present, because so many complex factors are involved as shown in 5.6.2.3. Determination of numerical values of the probability for the various radio services is urgently required and studies are being undertaken in several countries.

5.6.2.3 Probability factors

Probability of coincidence of adverse factors:

$$P = P_1 \times P_2 \times P_3 \times P_4 \times P_5 \times P_6 \times P_7 \times P_8 \times P_9 \times P_{10} \quad (35)$$

where

P_1 is the probability that the major lobe of the radiation is in the direction of the victim receiver;

P_2 is the probability of directional receiving aerials having maximum pick-up in the direction of the disturbing source;

P_3 is the probability that the victim receiver is stationary;

P_4 is the probability of equipment generating a disturbing signal on a critical frequency;

P_5 is the probability that the relevant harmonic is below the limit value;

P_6 is the probability that the type of disturbing signal being generated will produce a significant effect in the receiving system;

P_7 is the probability of coincident operation of the disturbing source and the receiving system;

P_8 is the probability of the disturbing source being within the distance at which interference is likely to occur;

P_9 is the probability of coincidence that the value of radiation at the edge of service area for the protected service just meets the limit for the RF disturbance;

P_{10} is the probability that buildings provide attenuation.

Table 3 – Tabulation of the method of determining limits for equipment in the frequency range 0,150 MHz to 960 MHz

Frequency band [MHz]	Radio service to be protected (non-exhaustive list)	Signal to be protected dB(μ V/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(μ V/m)	Distance from equipment at which signal is to be protected m	Attenuation law	Approximate equi-valent interference field at 20 m from equipment dB(μ v/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(μ V/m)	Corresponding limit at 30 m from boundary dB(μ V/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(μ v/m)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0,150 to 0,285	LF BC Aero-beacons											
0,285 to 0,490	Aero-beacons											
0,490 to 1,605	MF BC Aero-beacons											
1,605 to 4,00	Fixed links Aeromobile											
1,80 to 2,00	Amateur radio											
3,50 to 4,00	Amateur radio											
4,00 to 15,00	Fixed links Aeromobile											
7,00 to 7,30	Amateur radio											
10,10 to 10,15	Amateur radio											
14,00 to 14,35	Amateur radio											
15,00 to 20,00	Fixed links Aeromobile											
18,068 to 18,168	Amateur radio											

Table 3 *(continued)*

Frequency band	Radio service to be protected (non-exhaustive list)	Signal to be protected dB(µ V/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(µ V/m)	Distance from equipment at which signal is to be protected m	Attenuation law	Approximate equivalent interference field at 20 m from equipment dB(µ v/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(µ V/m)	Corresponding limit at 30 m from boundary dB(µ V/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(µ v/m)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
20,00 to 30,00	Fixed links Aeromobile											
21,00 to 21,45	Amateur radio											
24,89 to 24,99	Amateur radio											
28,00 to 29,70	Amateur radio											
30,00 to 68,00	TV BC Land mobile											
50,00 to 54,00	Amateur radio											
68,00 to 72,00	Audio BC Land mobile											
76,00 to 87,50	TV BC Land mobile											
87,50 to 108,00	Audio BC											
108,00 to 156,00	ILS Aero-mobiles Land mobile											
144,00 to 148,00	Amateur radio											
156,00 to 174,00	Land mobile											

Table 3 *(end)*

Frequency band	Radio service to be protected (non-exhaustive list)	Signal to be protected dB(µ V/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(µ V/m)	Distance from equipment at which signal is to be protected m	Attenuation law	Approximate equivalent inter-ference field at 20 m from equipment dB(µ v/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(µ V/m)	Corresponding limit at 30 m from boundary dB(µ V/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(µ v/m)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
216,00 to 400,00	ILS											
223,00 to 230,00	Amateur radio											
400,00 to 470,00	Fixed links Land mobile											
430,00 to 440,00	Amateur radio											
470,00 to 585,00	TV BC											
585,00 to 614,00	Aeronav TV BC											
614,00 to 854,00	TV BC											
854,00 to 960,00	Land mobile											
902,00 to 928,00	Amateur radio											

NOTE Explanation of column headings:

(3) Median value of the field strength to be protected at the edge of service area: to be derived from ITU regulations and ITU recommendations as appropriate.

(4) Protection ratio. The signal-to-interference ratio required to protect the radio service from interference with the characteristics of the signal generated by the disturbance source (for example, frequency stability, etc.). This is the value to be used in the derivation of limits and is not necessarily the same protection ratio as recommended by ITU for planning purposes.

(6) The mean minimum distance from the disturbance source at which receiving installations of the relevant radio service are normally installed. Disturbance sources at a different distance will be allowed for in the probability factor.

(9) The attenuation provided by buildings in which the disturbance source is installed. Experience has shown that 10 dB is a normal practical value.

5.6.3 Application of limits

The CISPR has traditionally adopted the view that there should be only one limit for each type of appliance. In the past, this approach has had considerable merit, but was increasingly difficult to sustain. Thus, it has been found useful to introduce several classes of limits, e.g. for disturbances from RF ISM equipment (see CISPR 11).

5.6.4 Overview of proposals for determination of disturbance limits for a given type of equipment

5.6.4.1 Determination of limits from practical experience

The exponents of this approach state simply that limits in use in their own country have been proved by practical experience to give adequate protection.

This is a powerful argument which cannot be ignored. The technical evaluation of coupling between sources of interference and communication services is very complex and virtually impossible to define precisely in mathematical or practical terms mainly because control of the various parameters is impossible and the spreads on measured values are very wide. Experience is therefore valuable. Unfortunately, the same factors which make experience valuable tend to militate against the acceptance of this approach unless the experience gained in a sufficiently large number of countries leads to similar conclusions. In this case, however, there is not a sufficiently large number of countries supporting the unqualified application of the actual limits but there is clearly a need to support the approach as one factor in the consideration of limits.

5.6.4.2 User and manufacturer responsibility for avoidance of interference

In a number of countries, user regulations are in force.

User limits may take one of several form outlines as follows:

a) regulations may require users of an appliance to meet certain limits if interference is caused;
b) if interference is caused, regulation may require an user of an appliance to cease operation until the interference is abated;
c) regulations based on the licensing of operation of a certain type of apparatus.

These approaches on their own satisfy neither the ITU/CISPR criteria for avoidance of interference nor the CISPR requirements for avoidance of technical barriers to trade. User limits would probably, in any case, be quite unacceptable in a number of countries as they place the user in an unfavourable position legally, financially and technically.

User regulations in conjunction with manufacturer regulations are a different matter. In these the user may be required to maintain suppression to the standard of new equipment and his financial, legal and technical obligations are therefore clear.

Examples of limits which are in use for user-only regulations are those in force in the United Kingdom for industrial radio-frequency heaters in the frequency range 0,15 MHz to 1 000 MHz. These broadly conform with the present CISPR limits with a provision of a 10 dB more stringent limit where interference is caused to safety of life services.

Other examples are the USA regulations which take the form described in item b) and the German regulations which take the form of item c). In the USA, the limits for RF ISM appliances are considerably less stringent than those recommended by CISPR.

5.6.4.3 Calculation of limits on a worst-case basis

This method of arriving at limits is intended to provide a high degree of protection for all radio communication services. Limits are calculated using minimum values of field strength to be protected, high values of protection ratio, maximum coupling between disturbance sources and radio communication receivers, and minimum values of attenuation with distance of the disturbing signal.

At first sight, this approach might seem to be ideal as it would, if implemented, lead to an ideal situation of very low values of man-made ambient radio-frequency noise. The cost to society of the adoption of such limits, however, would be high and it would be impossible, with present technology, to continue to operate many electrical devices, which would not contribute to the welfare and health of the human race.

5.6.4.4 Determination of limits by means of statistical evaluation

This approach states that the control of radio interference has to be treated statistically because the many factors involved are not under the control of the engineer and those parameters which are capable of measurement have very wide spreads of values.

The statistical evaluation approach has to overcome these difficulties. It should satisfy the communicator that communication services will receive adequate protection under normal circumstances of correct use, and the manufacturers and users of electrical equipment that economic, operational and safety considerations are being correctly taken into account.

5.6.5 Rationale for determination of CISPR limits in the frequency range below 30 MHz

5.6.5.1 General

With this subclause, a method for the estimation of disturbance limits for a given type of equipment is described. This approach can be applied for the frequency range below 30 MHz. For radiation coupling, dependence of the permissible disturbance field strength from the wanted signal μ_w, the signal-to-disturbance ratio R_p, and other influence factors can be estimated based on Equations (21) and (22) found in 5.5.

This model should be used by Product Committees to determine the disturbance limits measured on a EUT in standardized test sites. This model is considered suitable for point source magnetic field devices and not for distributed or complex systems.

Ten probability or influence factors P_1 to P_{10} have to be considered according to 5.6.2.3. However, for better alignment with terminology used for statistics the ten influence factors P_1 to P_{10} are further treated in their mean values as μ_{P1} to μ_{P10}. It shall be noted that the values for μ_{P1} to μ_{P10} can be used in logarithmic terms (i.e. in dB) only.

Taking into account Equation (22) we can write

$$E_{Limit} = \mu_i + t_\beta \sigma_i \quad (36)$$

Then taking equation (21) into account, noting that t_β = 0,84, and the limit becomes:

$$E_{Limit} = \mu_w - R_p + \mu_{P1} + \mu_{P2} + \mu_{P3} + \mu_{P4} + \mu_{P5} + \mu_{P6} + \mu_{P7} + \mu_{P8} + \mu_{P9} + \mu_{P10}$$

$$+ t_\beta \sigma_i - t_\alpha (\sigma_{P1}^2 + \sigma_{P2}^2 + \sigma_{P3}^2 + \sigma_{P4}^2 + \sigma_{P5}^2 + \sigma_{P6}^2 + \sigma_{P7}^2 + \sigma_{P8}^2 + \sigma_{P9}^2 + \sigma_{P10}^2)^{1/2} \quad (37)$$

where

E_{Limit} is the mean value of the permissible disturbance field strength at a specified distance *d* from the disturbance source;

μ_w is the minimum value of the wanted field strength at the edge of the service area of the radio service concerned;

R_p is the minimum acceptable value of the signal-to-disturbance ratio (i.e. the protection ratio) at the receiver's antenna port or feeding point;

μ_{P1} is the mean value of the main lobes of the magnetic dipole radiation in the direction of the victim receiver;

σ_{P1} is the standard deviation of P_1;

μ_{P2} is the expected mean value when the directional receiving antenna has its maximum pick-up in direction of the disturbance source;

μ_{P3} is the expected mean value when the victim receiver is stationary;

μ_{P4} is the expected mean value when there is equipment generating a disturbing signal on a critical frequency;

μ_{P5} is the expected mean margin when the relevant harmonic is below the limit value;

μ_{P6} is the expected mean value when the type of disturbance signal generated will produce a significant effect in the receiving system;

μ_{P7} is the expected mean value when the operation of the disturbance source is coincident with the receiving system;

μ_{P8} is the expected mean value when the disturbance source is located in a distance to the receiving system within which interference is likely to occur;

μ_{P9} is the expected mean value when the value of radiation at the edge of service area for the protected service just meets the limit for the RF disturbance;

μ_{P10} is the expected mean value when buildings provide attenuation.

Equation (37) is valid for mean values of influence factors (given in dB) assuming a log-normal distribution of their figures. Notice that the latter may not be fulfilled for each factor in each individual case. By inserting appropriate practical figures, Equation (37) can be used to estimate a limit E_{Limit} for the permissible disturbance field strength.

NOTE Within these calculations, 20 log has been utilized for distance elements and 10 log for the others, assuming power and not voltage.

5.6.5.2 Consideration and estimated values of μ_{P1} to μ_{P10}

5.6.5.2.1 Radiation pattern of the disturbance source (μ_{P1})

5.6.5.2.1.1 Consideration of μ_{P1}

The horizontal plane radiation pattern on a small purely magnetic antenna is described in dB unit by

$$G(\varphi) = G_{max} + 20 \log (\sin(\varphi)) \tag{38}$$

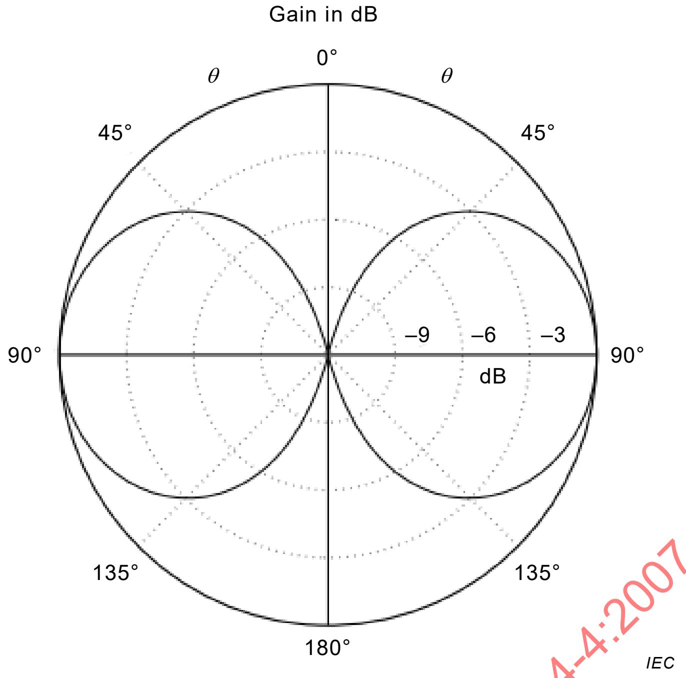


Figure 8 – horizontal plane radiation pattern on a small purely magnetic antenna

In the general case the victim may be in any possible direction with equal-probability. The mean value and standard deviation of the gain can be calculated by the following averages over half of the circle.

$$G_{avg} = Avg(G(\varphi)) \equiv \frac{1}{\pi} \times \int_0^{\pi} G(\varphi) d\varphi \qquad (39)$$

$$\sigma_G{}^2 = Avg\left(G(\varphi)^2\right) - \left(Avg(G(\varphi)\right)^2 = \frac{1}{\pi}\int_0^{\pi} (G(\varphi))^2 d\varphi - G_{avg}{}^2 \qquad (40)$$

Numerical calculation of Equations (39) and (40) gives the average gain $G_{avg} = G_{max} - 6,0$ dB and the standard deviation $\sigma_G = 7,9$ dB, which lead to $\mu_{P1} = G_{max} - G_{avg} = 6$ dB and $\sigma_G = 7,9$ dB

5.6.5.2.1.2 Estimation for the μ_{P1}

$\mu_{P1} = 6$ dB, $\sigma_{P1} = 8$ dB

5.6.5.2.2 Antenna gain of the victim to the disturbance source (μ_{P2}) (the directional receiving antenna have its maximum pick-up in direction of the disturbance source)

5.6.5.2.2.1 Consideration of μ_{P2}

In the frequency range below 30 MHz, a typical receiving antenna used with broadcast receivers is a rod antenna. Other antennas are also used. These antenna gains can vary to as much as –10 dB to 10 dB, however it can be assumed that 67 % of all antennas show a gain of within 3 dB of an isotropic antenna.

5.6.5.2.2.2 Estimation for the possible range of μ_{P2}

$$\mu_{P2} = -3 \text{ dB}, \sigma_{P2} = 3 \text{ dB}$$

5.6.5.2.3 Stationary receiver (μ_{P3})

5.6.5.2.3.1 Consideration of μ_{P3}

Below 30 MHz, it is likely that the victim receiver will be stationary; hence the value should be 0 dB.

5.6.5.2.3.2 Estimation for the possible range of μ_{P3}

$$\mu_{P3} = 0 \text{ dB}, \sigma_{P3} = 0 \text{ dB}$$

5.6.5.2.4 Equipment generating a disturbing signal at a critical frequency and relevant harmonics (μ_{P4})

5.6.5.2.4.1 Consideration of μ_{P4}

For the source of the magnetic disturbance from monitors and plasma TVs, the issue will appear for the fundamental frequency and the harmonics. Assuming the fundamental emission from the disturbance source is at 250 kHz and its harmonics will occupy approximately in the ratio of 5:1. Based upon a variation of ±25 kHz, giving a value of 50 kHz (7 dB).

For the source of the magnetic disturbance from induction cooking equipment, the issue will appear from the fundamental frequency and the harmonics. Assuming the fundamental emission from the disturbance source is at 50 kHz and its harmonics will occupy approximately in the ratio of 2:1. Based upon a variation of ±12,5 kHz, giving a value of 25 kHz (3 dB).

NOTE 1 The values below were derived from 10 log (1/5) = –7 dB and 10 log (1/2) = –3 dB hence the mean values 5 dB and the range of 2 dB.

NOTE 2 Other sources of disturbance may be from electrical car charging stations, phone charging systems and these are estimated to give similar values.

We have assumed no frequency dependency relevant to the limits.

A typical response of a source of magnetic field disturbance is present in Figure 9.

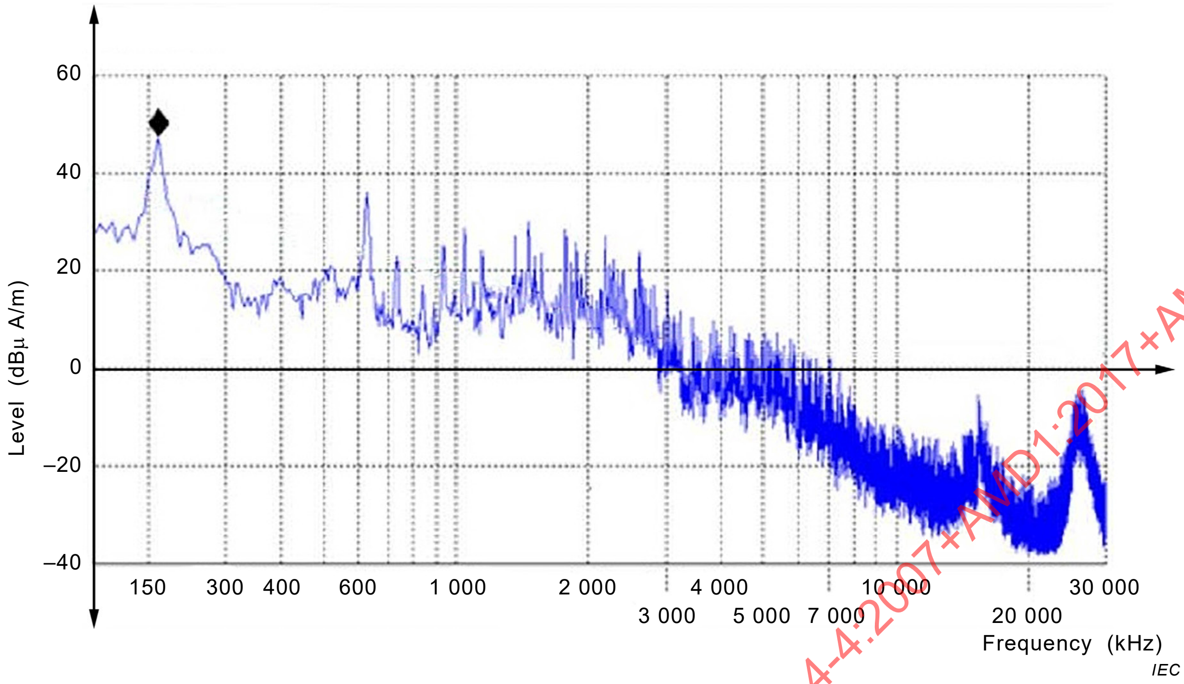


Figure 9 – typical source of magnetic field disturbance

5.6.5.2.4.2 Estimation for the possible range of μ_{P4}

$$\mu_{P4} = 5 \text{ dB, Range } \sigma_{P4} = 2 \text{ dB}$$

5.6.5.2.5 Margin that the relevant harmonics are below the limit value (μ_{P5})

5.6.5.2.5.1 Consideration of μ_{P5}

This value has been covered in μ_{P4}.

5.6.5.2.5.2 Estimation for the possible range of μ_{P5}

This value has been covered in μ_{P4}.

5.6.5.2.6 Expected mean value that the type of disturbance signal generated will produce a significant effect in the receiving system (μ_{P6})

5.6.5.2.6.1 Consideration of μ_{P6}

In the frequency range below 30 MHz, since the bandwidth of the unwanted signal and bandwidth of the receiver are of similar values, μ_{P6} should be set to 0 dB.

For the example of plasma TVs and induction cookers in the frequency range below 30 MHz, typically since the bandwidth of the disturbance source is greater than the bandwidth of the receiver, μ_{P6} should be set to 0 dB.

NOTE AC mains cable is not an issue of interference to radio receivers at the frequency below 30 MHz because this aspect is already covered by the conducted emission requirement defined in the standard.

5.6.5.2.6.2 Estimation for the possible range of μ_{P6}

$$\mu_{P6} = 0 \text{ dB, Range } \sigma_{P6} = 0 \text{ dB}$$

5.6.5.2.7 Expected mean value that the operation of the disturbance source is coincident with the receiving system operation of the disturbance source (μ_{P7})

5.6.5.2.7.1 Consideration of μ_{P7}

In the case that a receiver is operated for 24 hours, from the typical sources in 24 hours per day, plasma TV is 8 hours, PV Inverter 8 hours and induction cookers 2 hours operated.

NOTE The estimated values given in 5.6.6.2.7.2 were derived by 10 log (time of operation (hours) /24).

5.6.5.2.7.2 Estimation for the possible range of μ_{P7}

$$\mu_{P7} = 6{,}5 \text{ dB, Range } \sigma_{P7} = 3{,}5 \text{ dB}$$

5.6.5.2.8 The disturbance source is located in a distance to the receiving system within which interference is likely to occur (μ_{P8})

5.6.5.2.8.1 Consideration of μ_{P8}

The limit of the disturbance is specified for the test site with a normative fixed measurement distance *d*. In practice, the actual distance *r* between the disturbance source and the victim is usually quite different when the victim is used as intended.

The normative measurement distance *d* is 3 m. The ratio of the two distances *r* and *d* determines the additional attenuation.

The estimated value μ_{P8} usually increases the permissible limit and has to be added on the right hand side of Equation (37).

5.6.5.2.8.2 Estimation for the possible range of μ_{P8}

The value of μ_{P8} is calculated by:

$$\mu_{P8} = x \times 20 \log (r / d) \qquad (41)$$

where

r is the actual distance between source and victim;

d is the measurement distance;

x is the wave propagation coefficient, typical value to be determined based upon Annex B.

The estimated distance has to take into account the average distance for the intended use of the radio equipment. Inserting practical distances into Equation (41) will provide the possible range of μ_{P8}.

5.6.5.2.9 The value of radiation at the edge of service area for the protected service (μ_{P9})

5.6.5.2.9.1 Consideration of μ_{P9}

Due to propagation complexities related to the transmission properties relating to this frequency range (including solar storms, variation of the reflecting condition at the ionosphere and the time of day) it is difficult to define actual coverage areas of the radio service. There will still be areas were the service will have sufficient signals and other areas where there will be insufficient. Hence a basic approximation could be based upon a simple circularly response and the ratio between the two different coverage areas.

5.6.5.2.9.2 Estimation for the possible range of μ_{P9}

$$\mu_{P9} = 3 \text{ dB, Range } \sigma_{P9} = 3 \text{ dB}$$

5.6.5.2.10 The expected mean value that buildings provide attenuation of the building (μ_{P10})

5.6.5.2.10.1 Consideration of μ_{P10}

In this frequency range the worst case attenuation of buildings will be 0 dB.

NOTE Depending on the situation, building attenuation can be taken into account. Any attenuation may impact both the reception of the radio service and the amount of interference source observed. Hence this may need to be taken into account with the performance of the receiving antenna.

5.6.5.2.10.2 Estimation for the possible range of μ_{P10}

$$\mu_{P10} = 0 \text{ dB, Range } \sigma_{P10} = 0 \text{ dB}$$

5.6.5.3 Rationale for determination of CISPR limits for photovoltaic (PV) power generating systems

For a model for the derivation of limits for photovoltaic (PV) power generating systems see Annex C.

5.6.5.4 Rationale for determination of CISPR limits for in-house extra low voltage (ELV) lighting installations

For a model for the estimation of radiation from in-house extra low voltage (ELV) lighting installations see Annex D.

5.6.6 Model for limits for the magnetic component of the disturbance field strength for the protection of radio reception in the range below 30 MHz

5.6.6.1 General

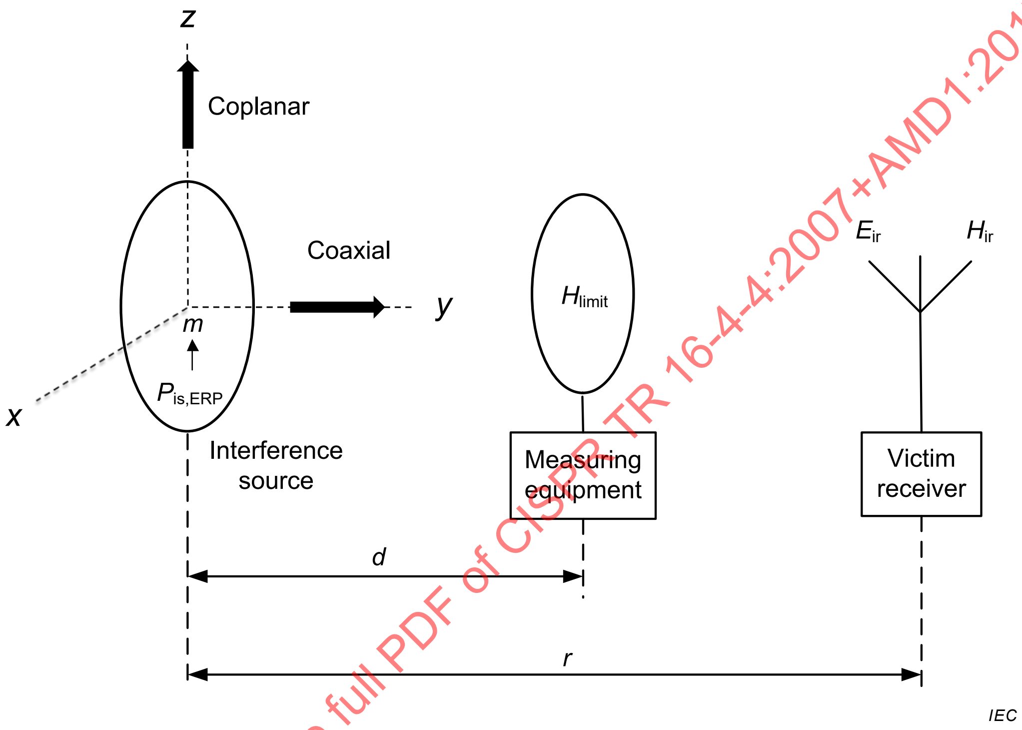
Recently, new electric or electronic devices having unintentional emissions below 30 MHz were introduced in the market. As the classical examples of these devices, there are plasma TV sets, power line communications devices, wireless power transfer, induction cooking devices, and so on. As the devices have been using increasingly, it is required to establish an appropriate model for deriving radiation limits in order to protect existing radio services at frequencies below 30 MHz.

This document contains statistics of complaints and mathematical models for the calculation of electric field limits related to the protection of radio services without the consideration of magnetic radiation within the near field region. Hence, development of other analytical models is required for the derivation of radiation limits on the devices having magnetic disturbances.

NOTE Other organisations also working within the area including CEPT and ITU-R.

5.6.6.2 Model for magnetic field limits below 30 MHz

This model is established for calculation magnetic field limits required for the protection of radio services against interference from various types of magnetic field sources using below 30 MHz. This method for calculation of magnetic field limits for protection of radio services below 30 MHz is depicted in Figure 10.



Key

m	magnetic dipole moment
E_{ir}	permissible interference electric field of victim receiver
H_{ir}	permissible interference magnetic field of victim receiver
$P_{is,ERP}$	effective radiated power of interference source at distance r from victim receiver
H_{limit}	magnetic field limits for interference source at measuring distance d, i.e. at the position of the antenna of the measuring equipment

Figure 10 – Model for magnetic field limit at measuring equipment

The permissible interference electric or magnetic field (E_{ir} or H_{ir}) of victim receiver can be derived from a method considering noise level or a method considering signal to disturbance ratio (R_P).

The method considering noise level is as follows:

E_{noise} (dBµV/m) of a victim service is corrected for the bandwidth of the victim receiver:

$$E_{noise} = E_{noise,b} + 10 \log (b_{victim} / b_{noise}) \tag{42}$$

where

b_{noise} is the measuring bandwidth of noise (kHz);

b_{victim} is the bandwidth of victim (kHz);

$E_{noise,b}$ is the electric field strength of noise from Recommendation ITU-R P.372 (dBμV/m).

NOTE $E_{noise,b}$ is defined by an ITU-R document as the background Gaussian noise level (excluding impulse and burst noises), assuming the reception with a loss-less omni-directional antenna and an ideal receiver. In the case that the antenna and feeder losses or receiver noise cannot be negligible, reference noise level should be defined by the system noise level.

In case of broadband interference, the bandwidth ratio *BWR* (dB) should be included to calculate the permissible interference electric field E_{ir} (dBμV/m):

$$E_{ir} = E_{noise} + \mathrm{BWR} \tag{43}$$

The bandwidth ratio is defined:

$$BWR = 10 \log (b_{measuring} - b_{victim}) \tag{44}$$

where

$b_{measuring}$ is measuring bandwidth of interferer (kHz).

When the bandwidth of the interfering signal is not wider than the victim receiver bandwidth, *BWR* = 0 dB should be assumed.

The method considering R_P is as follows.

In the case where the minimum received field strength E_{min} (dBμV/m) and the R_P (dB) of the victim receiver are known, the permissible interference electric field is calculated:

$$E_{ir} = E_{min} - R_P + BWR \tag{45}$$

From the permissible interference electric field, the permissible interference magnetic field H_{ir} (dBμA/m) can be obtained:

$$H_{ir} = E_{ir} - 51{,}5 \tag{46}$$

And then, the effective radiated power ERP of interference source at distance r from victim receiver can be determined by propagation attenuation loss between interference source and victim receiver. Propagation attenuation loss exponent is normally in the range of 2 to 4 (where 2 is for propagation in free space, 4 is for relatively lossy environments). In some environments, such as buildings, stadiums and other indoor environments, the propagation attenuation loss exponent can reach values in the range of 4 to 6.

The magnetic dipole moment *m* (Am^2) can be calculated from the effective radiated power of interference source at distance *r* from victim receiver, $P_{is,ERP}$ (kW) level.

$$m = \left(\frac{\lambda}{2\pi}\right)^2 \cdot \sqrt{50 \cdot P_{is,ERP}} \tag{47}$$

where

λ is the wavelength.

Finally, the magnetic field limits H_{limit} (A/m) for interference source at measuring distance d, i.e. at the position of the antenna of the measuring equipment can be calculated. The radiation direction from interference source is divided into coaxial and coplanar directions. The magnetic fields for these directions are computed by

$$H_{coaxial} = m \cdot \frac{\sqrt{\lambda_r^{\,2} + d^2}}{2\pi\,\lambda_r d^3} \tag{48}$$

$$H_{coplanar} = m \cdot \frac{\sqrt{\lambda_r^{\,4} - \lambda_r^{\,2} d^2 + d^4}}{4\pi\,\lambda_r^{\,2} d^3} \tag{49}$$

where

λ_r is the radian wavelength and is equal to $\lambda/2\pi$.

Then, H_{limit} is chosen to the maximum value of $H_{coaxial}$ and $H_{coplanar}$ in the view point of worst case as follows:

$$H_{limit} = \max\,(H_{coaxial},\ H_{coplanar}) \tag{50}$$

5.7 Rational for determination of CISPR limits in the frequency range above 1 GHz

NOTE References found in this subclause are listed in ther Bibliography.

5.7.1 Introduction

In 5.6, another suitable method for estimation of emission limits for a given type of equipment is described. The same or similar approach can be used for the frequency range above 1 GHz. For radiation coupling, dependence of the permissible disturbance field strength from the wanted signal μ_w, the signal-to-disturbance ratio R_p, and other influence factors can be estimated based on Equations (21) and (22) found in 5.5.

Seven probability or influence factors P_1 to P_7 have to be considered. These influence factors take into account e.g. the antenna gain, the attenuation of the disturbance field strength as in Equation (21), and other conditions. However, for better alignment with terminology used for statistics the seven influence factors P_1 to P_7 are further treated in their mean values as μ_{P1} to μ_{P7}. It shall be noted that the values for μ_{P1} to μ_{P7} can be used in logarithmic terms (i.e. in dB) only.

Taking into account Equation (22) we can write

$$E_{Limit} = \mu_i + t_\beta \sigma_i$$

with t_β = 0,84, and the limit becomes:

$$E_{Limit} = \mu_w - R_p + \mu_{P1} + \mu_{P2} + \mu_{P3} + \mu_{P4} + \mu_{P5} + \mu_{P6} + \mu_{P7}$$
$$+ t_\beta \sigma_i - t_\alpha (\sigma_{P1}^{\,2} + \sigma_{P2}^{\,2} + \sigma_{P3}^{\,2} + \sigma_{P4}^{\,2} + \sigma_{P5}^{\,2} + \sigma_{P6}^{\,2} + \sigma_{P7}^{\,2})^{1/2} \tag{36}$$

where:

E_{Limit} is the mean value of the permissible disturbance field strength at a specified distance d from the disturbance source;

μ_w is the minimum value of the wanted field strength at the edge of the service area of the radio service concerned;

R_p is the minimum acceptable value of the signal-to-disturbance ratio (i.e. the protection ratio) at the receiver's antenna port or feeding point;

μ_{P1} is the expected mean value that the major lobe of the disturbance field strength is not in the direction of the victim receiver;

μ_{P2} is the expected mean value that the directional receiving antenna does not have its maximum pick-up in direction of the disturbance source;

μ_{P3} is the expected mean value that for a mobile receiver the signal to noise ratio can be improved by keeping a certain distance to the disturbance source and that the mobile receiver is used well inside the respective radio service area;

μ_{P4} is the expected mean margin that the disturbance signal is below the limit;

μ_{P5} is the expected mean value that the type of disturbance signal generated will produce a significant effect in the receiving system;

μ_{P6} is the expected mean value that the disturbance source is located in a distance to the receiving system within which interference is likely to occur;

μ_{P7} is the expected mean value that buildings provide a certain degree of additional attenuation.

Due to lack of sufficient statistical data, Equation (36) is only analysed in terms of the mean values of the influence factors while neglecting the values for the standard deviation.

Equation (36) is valid for mean values of influence factors (given in dB) assuming a log-normal distribution of their figures. Notice that the latter may not be fulfilled for each factor in each individual case. By inserting appropriate practical figures, Equation (36) can be used to estimate a limit E_{Limit} for the permissible disturbance field strength.

For an estimation of limits related to the power of radiated disturbances, e.g. as needed for emission measurements in reverberation chambers, P_{Limit} can be derived from E_{Limit} (see Equation (36)) using the following equation:

$$E_{Limit}\,[\text{dB}(\mu\text{V/m})] = 104{,}8\text{ dB} + P_{limit}\,[\text{dB(mW)}] + G_S\,[\text{dB}] - 20\lg(d/d_{Ref)\,[\text{dB})]} \quad (36a)$$

If d is the measuring distance (e.g. 3 m), and G_S is the gain of the disturbance source, which can be replaced by μ_{P1}, then

$$P_{limit}\,[\text{dB(mW)}] = E_{Limit}\,[\text{dB}(\mu\text{V/m})] - 104{,}8\text{ dB} - \mu_{P1}\,[\text{dB}] + 20\lg(d/d_{Ref)\,[\text{dB})]}$$

and with d = 3 m (i.e. 20 lg$(d/d_{Ref)}$ = 9,5 dB) we get

$$P_{limit}\,[\text{dB(mW)}] = E_{Limit}\,[\text{dB}(\mu\text{V/m})] - 95{,}3\text{ dB} - \mu_{P1}\,[\text{dB}] \quad (36b)$$

5.7.2 Consideration and estimated values of μ_{P1} to μ_{P7}

5.7.2.1 Radiation pattern of the disturbance source (μ_{P1})

5.7.2.1.1 Consideration of μ_{P1}

Sources generating radiated disturbances in the frequency range above 1 GHz usually show directional radiation pattern which have one or more main lobes and also significant notches.

The influence factor describes the margin of an averaged pattern figure of the EUT to the disturbance level measured at maximum beam direction.

Factor μ_{P1} increases the permissible limit and has to be added on the right hand side of Equation (36b).

5.7.2.1.2 Estimation for the possible range of μ_{P1}

In [4] an antenna gain of about 6 dB is estimated for large EUTs, in the frequency range above 1 GHz. This could be interpreted such that on average, the disturbance field strength may be 6 dB below the maximum value measured on the test site.

In [5] it is estimated further that, for the frequency range above 1 GHz, measurement results obtained at the test site, on average will be about 6 dB below the maximum radiation of the disturbance sources. This means that the results obtained from test site measurements are, on average, significantly below the limit, owing to the radiation pattern. Reference [4] also gives evidence that for large increments of rotation the readings are on average 8,6 dB below the maximum, while with smaller increments the readings will be on average 3 dB below the maximum emission.

Radiation pattern of real EUTs are presented in [8]. These measurement results show that, in the frequency range 1 GHz to 3 GHz, the average radiation pattern is regularly about 3 dB to 6 dB below maximum radiation found at another nearby rotation position. It can also be seen that, at higher frequencies, the radiation pattern may branch more and more in each direction and that single beams with small beam widths appear.

Considering the facts in [4], [5], and [8] it is assumed that, on average, the disturbances are 3 to 8 dB below the maximum, meaning that:

μ_{P1} ranges from 3 dB to 8 dB.

5.7.2.2 Antenna gain of the victim to the disturbance source (μ_{P2})

5.7.2.2.1 Consideration of μ_{P2}

Radiated disturbances and wanted RF signals will usually reach the receiver's antenna from different directions. The gain G_w of the receiving antenna is available in direction of the wanted RF field strength. The disturbance field strength can be expected from a different direction, with the gain G_i. Therefore μ_{P2} represents the mean value of the difference of both gains. This difference gives the available gain G_{av} for the improvement of the actual signal to disturbance ratio R:

$$G_{av} = \mu_{P2} = G_w - G_i \qquad (37)$$

The estimated value μ_{P2} increases the permissible limit and has to be added on the right hand side of Equation (36).

5.7.2.2.2 Estimation for the possible range of μ_{P2}

The antenna gain G_w of the radio receiver in direction of the wanted RF field strength depends on the radio service and can assume values between 0 dB (for mobile radio services, such as GSM, DCS, or UMTS) and 80 dB (for certain fixed radio services). In the frequency management, a value of G_i = 6 dB is used for the gain in other directions if the gain in the main lobe of the receiver antenna is greater than 6 dB.

In respect of EMC the following range should be used:

$$\mu_{P2} = G_w - 6\,\text{dB}\Big|_{6\,\text{dB} < G_w \leq 12\,\text{dB}} \quad \text{and} \quad \mu_{P2} = 6\,\text{dB}\Big|_{G_w > 12\,\text{dB}}$$

5.7.2.3 Mobile receiver (μ_{P3})

5.7.2.3.1 Consideration of μ_{P3}

This factor takes into account that a mobile receiver can always be moved away from the disturbance source and that the receiver will be provided, inside the radio service area, with a wanted RF field strength which is stronger than the minimum wanted RF field strength at the edge of the service area.

The estimated value μ_{P3} increases the permissible limit and has to be added on the right hand side of Equation (36).

5.7.2.3.2 Estimation for the possible range of μ_{P3}

From a frequency management point of view, for mobile radio services and particularly for base stations there is a need for more RF channels if radiated disturbances increase within the wanted radio frequency (RF) band, in a given area and environment. This is the reason why the frequency management can only propose a factor of 0 dB, for μ_{P3}. From representatives of other branches of industry it is required that the worst case can not be used for the estimation of disturbance limits. From the latter perspective, it would be possible to tolerate values for factor μ_{P3} in the range of 6 dB.

Furthermore, the mobile receiver is used rather seldom at the edge of the service area, in particular if a cellular radio service is considered. Therefore the wanted RF field strength used for calculation of the permissible disturbance field strength should be, on average, higher than the minimum wanted RF field strength required at the edge of the service area.

Considering the physical laws, the wanted RF field strength decreases linearly with distance while the service area increases with the square of this distance. For consideration of the mobility of the receiver, the wanted RF field strength at the edge of half of the service area is used.

The service area depends on the distance by square root of the distance. The field strength depends on the distance linearly. This means:

$$0{,}5 \cdot A = \left(\frac{d}{\sqrt{2}}\right)^2 \cdot \frac{\pi}{4} \qquad (38)$$

and

$$E_w(d) = 7 \cdot \frac{\sqrt{P_w \cdot G_w}}{\left(\frac{d}{\sqrt{2}}\right)} \tag{39}$$

Under this condition the wanted RF field strength E_w used for calculation can be increased by 3 dB, compared to the minimum wanted RF field strength required at the edge of the service area. Instead of using an increased-by-3-dB wanted RF field strength for the calculation of the respective disturbance limit one can also continue to use the minimum wanted RF field strength required at the edge of the service area and add the 3 dB to the influence factor μ_{P3}.

The possibilities for mobile radio receivers to be used well inside a given service area and to extend the distance to the disturbance source by being moved away from that source should be taken into account by setting the range for the mean value μ_{P3} of the influence factor from 0 dB up to 9 dB:

μ_{P3} ranges from 0 dB to 9 dB.

5.7.2.4 Emission level of the disturbance source is below the limit (μ_{P4})

5.7.2.4.1 Consideration of μ_{P4}

Usually, disturbances from a certain source do not just meet the limits, but have a certain margin to them. Factor μ_{P4} counts for the estimated average of the minimum margin of the disturbance to the limit.

The estimated value μ_{P4} increases the permissible limit and has to be added on the right hand side of Equation (36).

5.7.2.4.2 Estimation for the possible range of μ_{P4}

An EUT conforms with the limit when the maximum disturbance emission is below (or equal to) the limit. This also means that the difference between the limit and the disturbance is greater than (or equal to) zero.

Contribution [7] contains an estimation of the margin to the limit for 49 samples of class A and class B IT equipment. The average margin to the FCC limit for all 49 products is about 12 dB.

The 273 measurement values of the margin to the limit reported in [7] are distributed over a range from -2,6 dB to +31,9 dB.

As a result of this investigation it can be assumed that μ_{P4} is usually in the range of:

μ_{P4} ranges from 0 dB to 24 dB.

5.7.2.5 Interference depending on the bandwidth of the radio service (μ_{P5})

5.7.2.5.1 Consideration of μ_{P5}

For continuous broadband disturbances, the interference potential to a receiving system depends on the wanted RF signal bandwidth of the victim receiver. The higher the wanted RF signal bandwidth B_{want} of the victim receiver or its respective radio service is, the higher the interference potential would be, compared to the RF bandwidth B_{meas} of the measurement receiver. That also means that the interference potential is lower if the RF bandwidth of the radio service is smaller than that of the measurement receiver. Eventually, the interference potential of a source of broadband disturbances also depends on the ratio of the bandwidth B_{noise} of the broadband disturbance to the bandwidth of the wanted radio signals B_{want} actually considered.

In practice, three cases may occur that require adequate consideration.

Case a) $B_{want} < B_{noise} < B_{meas}$

In this case, calculation of μ_{P5} shall deliver negative dB values, since not only one receiving channel may be interfered with, but several ones.

In view of this, the permissible broadband disturbance can be described by Equation (40a) as ratio of the bandwidth for the considered individual radio service to the bandwidth of the broadband disturbance:

$$E_p = E_m \sqrt{\frac{B_{want}}{B_{noise}}} \tag{40a}$$

where:

E_m is measured disturbance field strength;

E_p is permissible disturbance field strength for the considered radio service;

B_{noise} is bandwidth of the broadband disturbance;

B_{want} is bandwidth of the considered radio service for the wanted signal.

For estimation of the decrease required for the permissible disturbance field strength, the value of μ_{P5} can be calculated by Equation (41a):

$$\mu_{P5} = 10 \cdot \log_{10} \left[\frac{B_{want}}{B_{noise}} \right] \tag{41a}$$

Case b) $B_{meas} < B_{noise} < B_{want}$

In this case, calculation of μ_{P5} can deliver positive dB values, since the disturbance may not occupy the whole receiving channel of the victim receiver concerned.

In view of this, the permissible broadband disturbance can be described by Equation (40b) as ratio of the bandwidth of the broadband disturbance to the bandwidth of the measuring receiver:

$$E_p = E_m \sqrt{\frac{B_{noise}}{B_{meas}}} \tag{40b}$$

where:

E_m is measured disturbance field strength;

E_p is permissible disturbance field strength for the considered radio service;

B_{noise} is bandwidth of the broadband disturbance;

B_{meas} is bandwidth of the measurement receiver.

For estimation of a relaxation possible for the permissible disturbance field strength, the value of μ_{P5} can be calculated by Equation (41b):

$$\mu_{P5} = 10 \cdot \log_{10} \left[\frac{B_{noise}}{B_{meas}} \right] \tag{41b}$$

Case c) $B_{noise} > B_{meas}$ and B_{want}, respectively

In this case of true broadband disturbance, calculation of μ_{P5} can deliver positive as well as negative dB values, since the assessment result only depends on the ratio of the wanted RF signal bandwidth to the measurement bandwidth.

In view of this, the permissible broadband disturbance can be described by Equation (40c) as ratio of the bandwidth of the considered individual radio service to the measurement bandwidth:

$$E_p = E_m \sqrt{\frac{B_{want}}{B_{meas}}} \tag{40c}$$

where:

E_m is measured disturbance field strength;

E_p is permissible disturbance field strength for the considered radio service;

B_{meas} is bandwidth of the measuring receiver;

B_{want} is bandwidth of the considered radio service for the wanted signal.

For estimation of an increase or decrease allowed for the permissible disturbance field strength, the value μ_{P5} can be calculated by Equation (41c):

$$\mu_{P5} = 10 \cdot \log_{10} \left[\frac{B_{want}}{B_{meas}} \right] \tag{41c}$$

The estimated value of μ_{P5} for broadband services has to be added on the right hand side of Equation (36).

5.7.2.5.2 Estimation for the possible range of μ_{P5}

The value of μ_{P5} can be calculated by Equation (41) and is determined by the bandwidth of the considered radio service.

5.7.2.6 Ratio of the distance between source and victim to the measurement distance (μ_{P6})

5.7.2.6.1 Consideration of μ_{P6}

The limit of the disturbance emission is specified for the test site with a normative fixed measurement distance *d*. In practice, the actual distance *r* between the disturbance source and the victim is usually quite different when the victim is used as intended.

The normative measurement distance *d* is 3 m. The ratio of the two distances *r* and *d* determines the additional attenuation.

The estimated value μ_{P6} usually increases the permissible limit and has to be added on the right hand side of Equation (36).

5.7.2.6.2 Estimation for the possible range of μ_{P6}

The value of μ_{P6} is calculated by:

$$\mu_{P6} = x \cdot 20 \cdot \log_{10} \left[\frac{r}{d} \right] \tag{42}$$

where

r = actual distance between source and victim;

d = measurement distance;

x = wave propagation coefficient, which is 1 in free-space propagation and somewhat higher (1 to 1,5) for non-free-space propagation.

The estimated distance has to take into account the average distance for the intended use of the radio equipment. Inserting practical distances into Equation (42) will provide the possible range of μ_{P6}.

NOTE In special areas, where use of mobile radio communication equipment is not permitted, larger distances r can be used for calculation. The estimated limit is valid only for such environments.

5.7.2.7 Attenuation of the building (μ_{P7})

5.7.2.7.1 Consideration of μ_{P7}

An additional attenuation between the disturbance source and the victim reduces the level of disturbance and depends on the position of source and victim. Two options for calculating the permissible disturbance field strength are considered: option a), where the disturbance source and the victim are inside the building and option b), where one is inside the building and the other is outside.

The estimated value μ_{P7} increases the permissible limit and has to be added on the right hand side of Equation (36).

5.7.2.7.2 Estimation for the possible range of μ_{P7}

For option a) it is assumed that an attenuation value in the range of 0 dB to 6 dB is suitable. For option b), an attenuation value in the range of 2 dB to 20 dB is assumed.

Depending on the location of the victim and disturbance source it is proposed that the following be used:

μ_{P7} ranges from 0 dB to 20 dB.

5.7.3 Equivalent EMC environment below and above 1 GHz

In 5.6.4 it is also mentioned that calculation of limits based on statistics can not be the one and only way of estimating CISPR limits. Positive practical experience with existing limits is also a powerful argument. For this reason, the ratio of limits at about 1 GHz as borderline between existing limits and new limits can be considered. However, as radio services above 1 GHz are mainly based on different technologies they can be regarded more robust compared to the analogue techniques which were the basis for limits below 1 GHz. For the calculation it is assumed that radio services and applications operating at frequencies above or below 1 GHz are to be protected in the same way.

For such a comparison the same mobile radio service in the frequency range above 1 GHz as in the frequency range below 1 GHz may be used. For this comparison consideration of the limits of GSM (900 MHz) and DCS (1800 MHz) may be useful, owing to the fact that both radio services have comparable functional parameters.

Table 4 contains the relevant data of protected wanted RF field strength, the CISPR limit for measurements with a quasi-peak (QP) detector at a measurement distance of 10 m under free field conditions, and the procedure for the estimation of an equivalent limit at 1 800 MHz for the different measurement procedure under free-space wave propagation conditions, with a different detector type and a different measurement bandwidth.

Factor *x* (dB) takes into account a transposition of the appropriate limit from CISPR 22 at about 900 MHz from 10 m to 3 m measurement distance normally used for disturbance measurements in the frequency range above 1 GHz. This shall be added to the CISPR limit.

Factor *y* (dB) takes into account the transfer from free-field wave propagation conditions (as e.g. at OATS) to free-space wave propagation conditions as normally defined for disturbance measurements in the frequency range above 1 GHz. This shall be subtracted from the CISPR limit.

Eventually, the difference *d* between the estimated limit and the wanted RF field strength at 900 MHz can be used for estimation of the CISPR limit at 1 750 MHz.

Table 4 – Calculation of permissible limits for disturbances at about 1 800 MHz from existing CISPR limits in the frequency range of 900 MHz

	GSM at about 900 MHz	**DCS at about 1 800 MHz**
Protected wanted RF field strength	32 dB(μV/m)	42 dB(μV/m)
Transfer limit of 37 dB(μV/m) at 10 m to 3 m by addition of x dB	(37+x) dB(μV/m)	-
Transfer OATS to free space conditions by subtraction of y dB	(37+x-y) dB(μV/m)	-
Transfer QP to AV detector [a]	(37+x-y) dB(μV/m) + about z dB	-
Transfer 120 kHz to 1 MHz measurement bandwidth by addition of 9,2 dB	(37+x-y + z) dB(μV/m) + about 9,2 dB	-
Difference *d* between the CISPR limit for permissible disturbance and the wanted RF field strength at 900 MHz	*d* = [(37+x-y + z) dB + 9,2 dB] - 32 dB	-
Resulting limit for permissible disturbances at 1800 MHz	-	(42 + *d*) dB (μV/m)

[a] In case of CW-type disturbances the use of an average detector does not require additional corrections. However a factor z is provided for appropriate consideration of non-continuous disturbances.

5.7.4 Overview on parameters of radio communication services operating in the frequency range above 1 GHz and up to 16 GHz with effect to electromagnetic compatibility

Table 5 contains a list of radio communication services operating in the frequency range above 1 GHz and up to 16 GHz. It contains valuable data of radio parameters with relevance to EMC. The data set out in Table 5 can be used to calculate limits for permissible disturbances emanating from equipment, systems or even installations, in the frequency range above 1 GHz. For such calculations and estimations, the model set out in 5.7 should be used.

The readers and users of the present document are invited and encouraged to accomplish the entries in Table 5 by their own data and to submit their findings to Subcommittee H of CISPR, which is responsible for maintenance of this CISPR Report.

Table 5 – List of radio services, typical parameters, and influence factors

Radio system (name)	Receiving frequency band / MHz	Protected wanted field strength Ew/dB(µV/m)	Protection ratio R / dB	Tolerable interferer /dB(µV/m)	Bandwidth of radio service /kHz	Gain of victim antenna / dB	Operation time of receiver/ day (%)	Isolation distance / m	**P1**: gain of disturb. Source	**P2**: Gain of victim antenna	**P3**, h: Victim is mobile	**P4**: emission below limit	**P5**: Type of emission Broadband correc.	**P6**, l: distance to victim	**P7**, f-manag.: building attenuation	**P7**, manufact.: building attenuation	Permissible disturb. manufacture Ed/dB(µV/m)	Permissible disturb. F-management Ed/dB(µV/m)
Navigation aid	1 085 - 1 095	56	8	48	10 000	11												
Radioamateur	1 240 - 1 300	-5	10	-15	3	6												
Radar	1 250 - 1 260	31	20	11	500	35												
T-DAB	1 452 - 1 462	43	28	15	1 540	0												
	1 452 - 1 463	43	28	15	1 540	0												
GPS	1 575.42	5	-36	41	1 000	0												
GSM 1800 base	1 710 - 1 785	38	9	29	200	18												
GSM 1800 mobile	1 805 - 1 880	40,5	9	31,5	200	0												
	1 805 - 1 881	42	9	33	200	0												
GSM	1 710 - 1 805	38	9	29	200	0												
	1 710 - 1 806	38	9	29	200	0												
DECT	1 880 - 1 900	59	10	49	1 700	0												
UMTS FDD base	1 920 - 1 980	23	-6	29	5 000	18												
UMTS FDD mobil	2 110 - 2 270	26	-9	35	5 000	0												
UMTS TDD	1 900 - 2 025	25	-10	35	5 000	35												
UMTS extension	2 500 - 2 690	26	-9	35	5 000	0												
Radioamateur	2 320 - 2 400	4,5	6	-1,5	3	6												
BOS/ Broadcast	2 320 - 2 500	69	30	39	14 000	6												
Fixed serv. PMP	2 540 - 2 670	43	26	17	14 000	6												
Radar	2 700 - 2 900	37	10	27	1 000	33												
Radioamateur	3 400 - 3 475	8	10	-2	3	12												
Fixed serv. PMP	3 410 - 3 580	46	36	10	14 000	18												
Fixed serv. PMP	3 800 - 4 200	49	36	13	29 000	45												
HPERLAN/1	5 200	68	12	56,3	23 500	0												
WLAN	5 150 - 5 725	69	16	53	20 000	0												
Radioamateur	5 650 - 5 850	12	10	2	3	12												
Demo.radio	5 725 - 5 875	38	10	28	200	0												

Table 5 *(continued)*

Radio system (name)	Receiving frequency band / MHz	Protected wanted field strength Ew/dB(µV/m)	Protection ratio R / dB	Tolerable interferer /dB(µV/m)	Bandwidth of radio service /kHz	Gain of victim antenna / dB	Operation time of receiver/ day (%)	Isolation distance / m	**P1**: gain of disturb. Source	**P2**: Gain of victim antenna	**P3**, h: Victim is mobile	**P4**: emission below limit	**P5**: Type of emission Broadband correc.	**P6**, l: distance to victim	**P7**, f-manag.: building attenuation	**P7**, manufact.: building attenuation	Permissible disturb. manufacture Ed/dB(µV/m)	Permissible disturb. F-management Ed/dB(µV/m)
Remote control	5 725 - 5 875	42	10	32	2500	0												
Fixed serv. PMP	5 930 - 6 419	54	36	18	30 000	60												
Fixed service	6 425 - 7 125	56	36	20	40 000	50												
Fixed service	7 137 - 7 413	69	36	33	14 000	44												
Narrowb, fixed services	7 413 - 7 425	30	36	-6	100	44												
Fixed service	7 425 - 7 725	55	36	19	28 000	44												
Demo.radio	9 235 - 9 475	42	10	32	200	0												
Radar	9 185 - 9 170	42	10	32	2 500	34												
Radio amateur	10 000 - 10500	17	6	11	3	12												
Sat. Broad./1MHz	11 400 - 12 400	60	23	37	1 000	0												
Fixed service	12 750 - 13 250	60	36	24	28 000	49												
Fixed service	15 320 - 15 350	59	36	23	14 000	47												

Annex A

Excerpt from CISPR Report No. 31 Values of mains decoupling factor in the range 0,1 MHz to 200 MHz

(This Report provides a partial answer to Study Question No. 54/1 of 1964 which remains under consideration.)

(Stresa, 1967)

1. Figure 1, page 50, shows median values, standard deviations and minimum values of mains decoupling factor, defined as the ratio of voltage injected into the mains and the resultant voltage measured at the end of a terminated aerial feeder. The values indicated were obtained by various authors (see references below) under different conditions of measurement. They generally apply to an asymmetrical source connected in a random manner between the "phase" and "null" conductor of a single phase mains supply system * and to well screened receivers. In the frequency range up to 30 MHz, the data apply mainly to receiving installations with indoor aerials (excluding ferrite aerials); above this frequency, most of the coupling measurements were made at installations with outdoor aerials.
2. In Figure 2, page 51, an attempt is made to synthesize the available data, taking as far as possible account of the differences between the various sources. It is believed that the curves shown represent a conservative estimate of the decoupling factor to be expected between sources and receivers located in the same or immediately adjoining apartments of the same building.
3. Figure 3, page 51, shows typical distributions of measured values which may be used to determine decoupling factors for a percentage of cases other than 50%.

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vi) Document C.I.S.P.R.(U.K.)376.

vii) Documents C.I.S.P.R./WG6(U.K./McLachlan) 6,7.

Secretarial Note. The C.I.S.P.R. Secretariat does not hold copies of the above documents. If these are required, application should be made to the National Corresponding Member of the Working Group concerned.

* In the United Kingdom measurements, the asymmetrical source was connected between the earth conductor and the line and neutral conductors connected together in the manner indicated in Figure 4A, page 52.

APPENDIX A TO REPORT 31

In the measurement of mains decoupling factor, the following principal requirements must be observed:

1. The internal resistance, the symmetry to ground and the polarity of connection to the mains of the signal source used for measurement should correspond to similar parameters of actual appliances.
2. The output voltage of the source should be measured by the methods used for checking compliance with limits.
3. Throughout the whole measurement, actual receiving aerials as found at the measured locations should be used.
4. The input impedance of the measuring receiver should approximate, as closely as possible, to the value of the input impedance of normal receivers.
5. The sites investigated should correspond qualitatively and quantitatively to the location at which the results will be used.

The statistical evaluation is usually carried out as if the data belonged to a single statistical set of random values. Using this method, the range of distances up to which measurements are carried out becomes very important because the average value and spread measured at a given site depends not only on the properties of the electrical installations and on the building attenuation, but also to a great extent on the area around the source covered by measurements. For example, by increasing this area, it is possible to obtain a lower average and higher spread of the decoupling factor. It is therefore necessary to limit the extent of data used for statistical evaluation to decoupling factors for which interference might still be expected with a given terminal voltage limit, a given protection ratio, and a given minimum usable sensitivity of receivers.

The decoupling factor a_{max} beyond which interference is no longer likely to occur and which ought consequently to be excluded from the evaluation, may be calculated from the following equation:

$$L - a_{max} = s - p$$

where

a_{max} = maximum decoupling factor (in decibels)

L = terminal voltage limit (in decibels over 1 µV)

s = minimum usable sensitivity of receivers considered (in decibels over 1 µV)

p = protection ratio (in decibels).

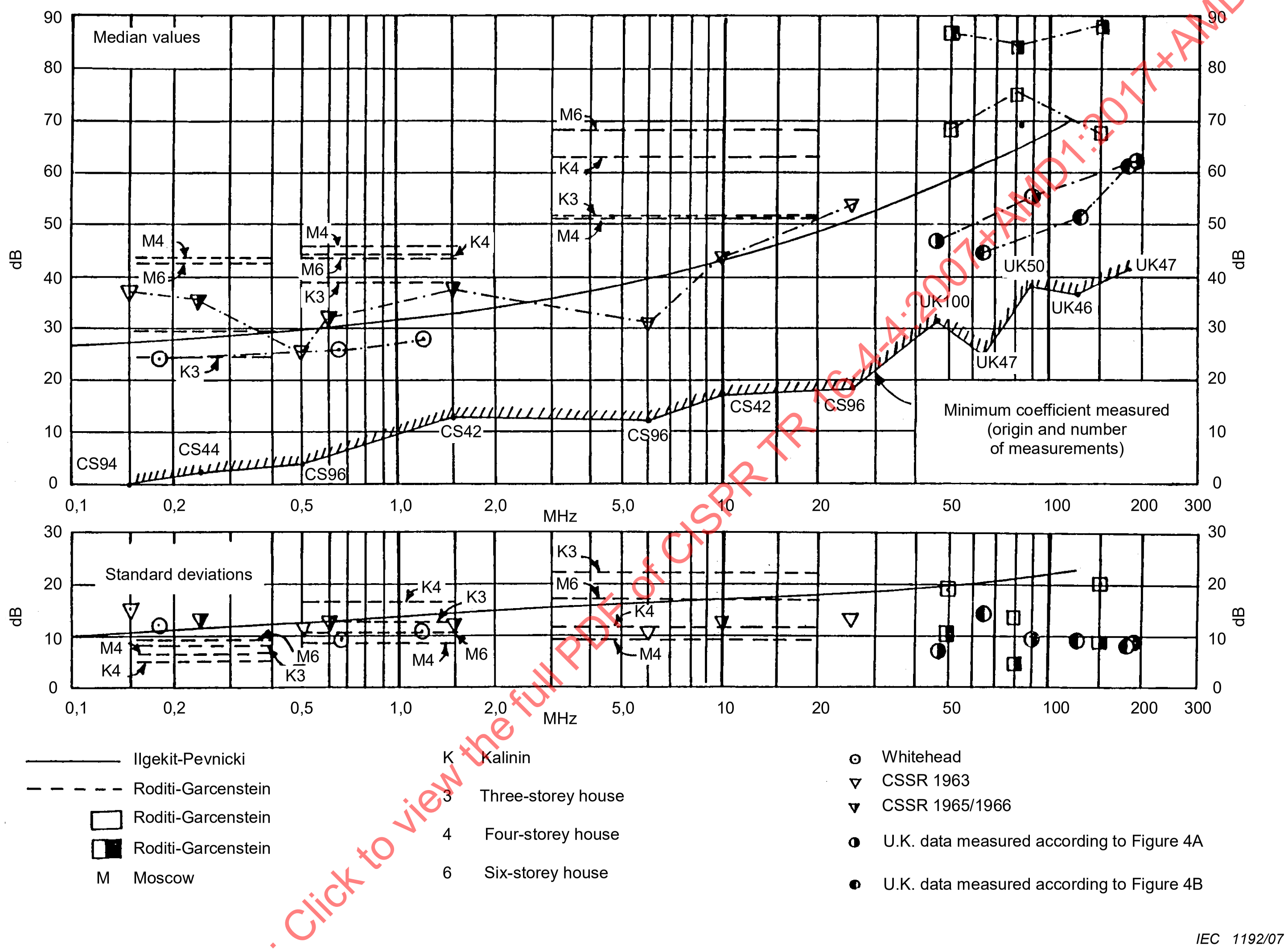

Figure A.1 – Mains decoupling coefficient as measured by various authors

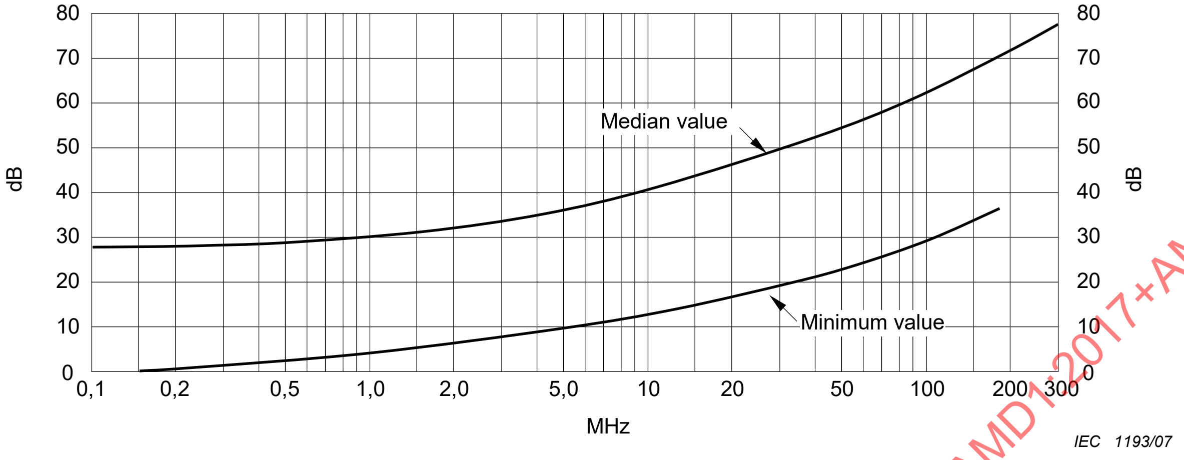

Figure A.2 – Median and minimum values of mains decoupling factor for the range 0,1 MHz to 200 MHz

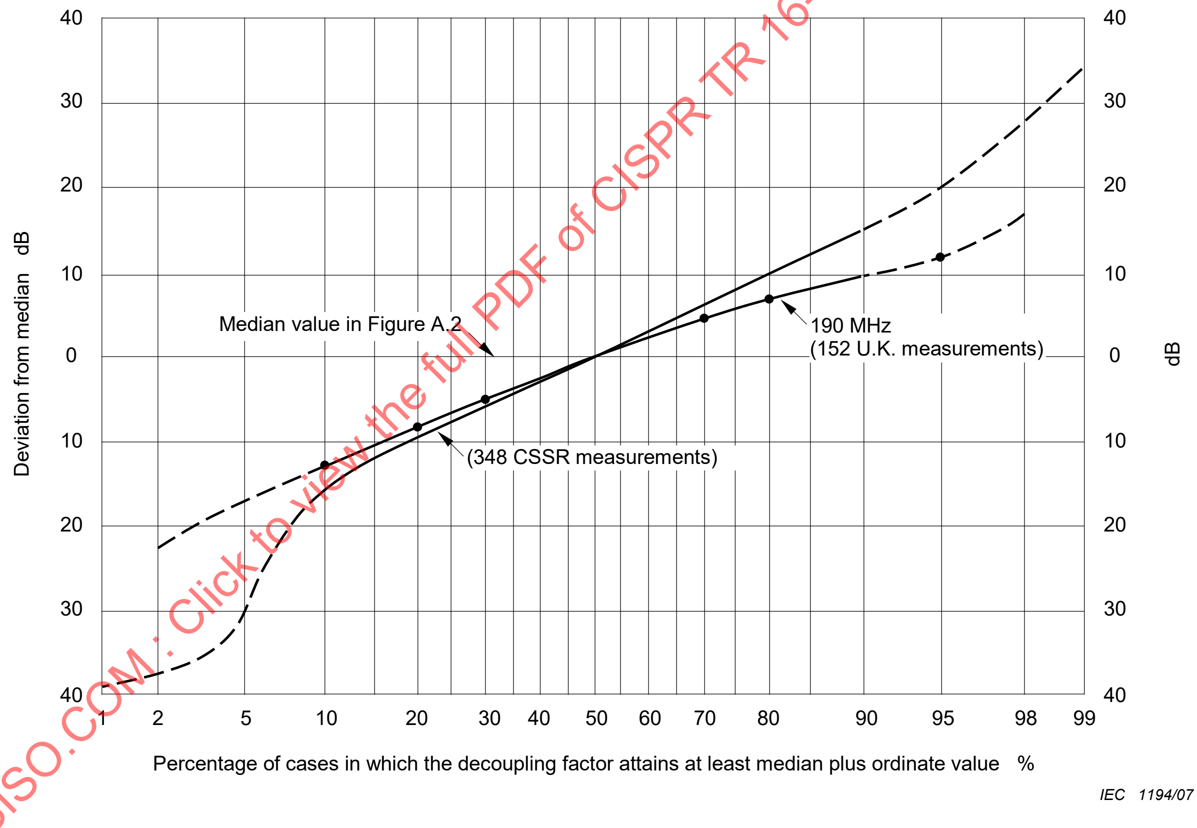

Figure A.3 – Typical distributions of deviations from median value of decoupling factor as indicated in Figure A.2

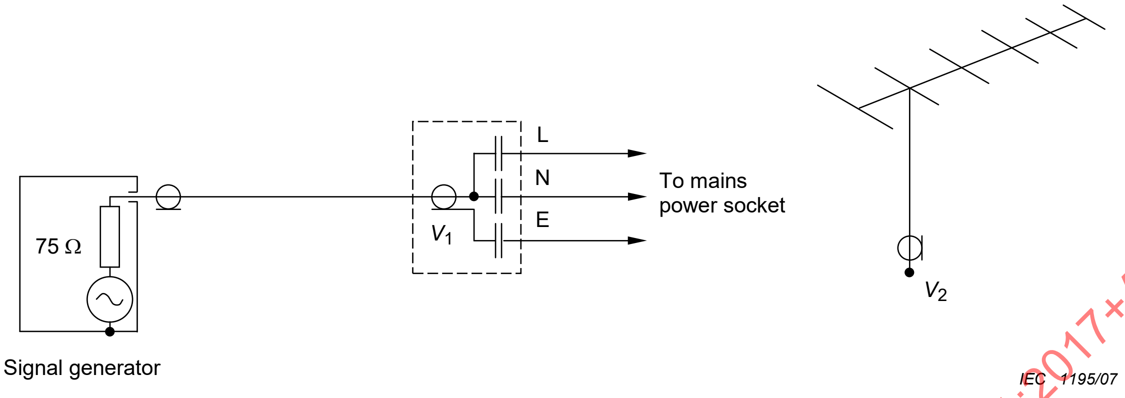

Figure A – Measurement with signal generator

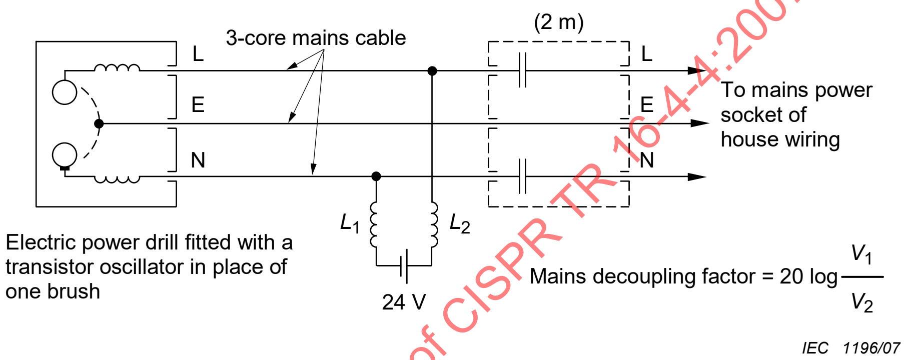

Figure B – Measurement using actual appliance

Figure A.4 – Measurement of the mains decoupling factor

Annex B
(informative)

Conversion of H-field limits below 30 MHz for measurement distances

B.1 Background

In order to determine the H-field conversion factor within the boundary of the test environment containing the ground plane, a commercial 3D full wave simulation tool has been used and the calculation thereof along with measurement records are provided in the following paragraphs.

Figure B.1 illustrates a designed model using a commercial tool. The dimension of the ground plane is 30 m x 40 m. The radius of the loop antenna, which is 0,6 m and the centre of the antenna is 1,3 m above the surface of the ground plane. For the measurement of field, the probes are located at 3 m and 10 m, both at coaxial and coplanar direction (a: coaxial at 3 m, b: coaxial at 10 m, c: coplanar at 3 m, d: coplanar at 10 m).

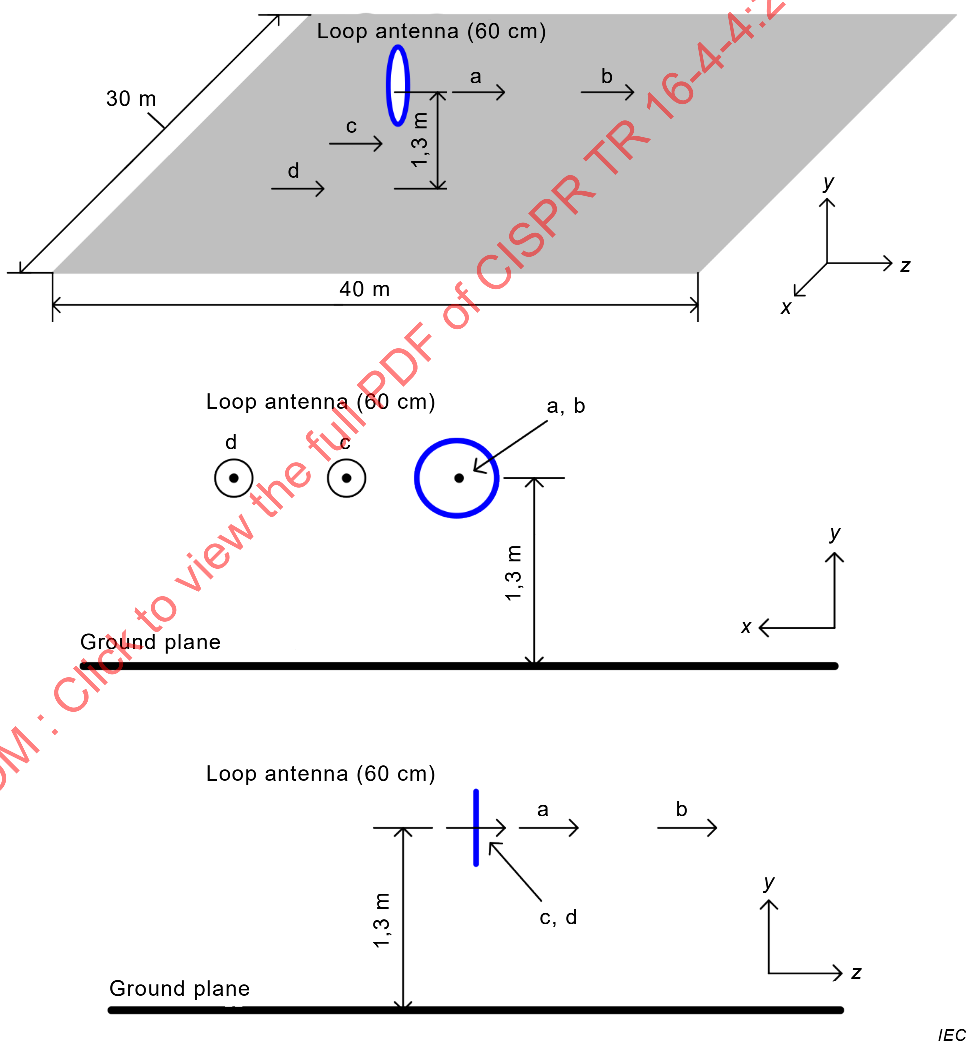

Figure B.1 – Commercial tool model for H-field conversion

Figure B.2 depicts another designed model using a commercial tool, and the ground plane has been removed in order to apply image theory with an additional virtual loop antenna positioned at 1,3 m below the ground plane that has been removed. This model is intended to measure coaxial and coplanar direction component from the same probe.

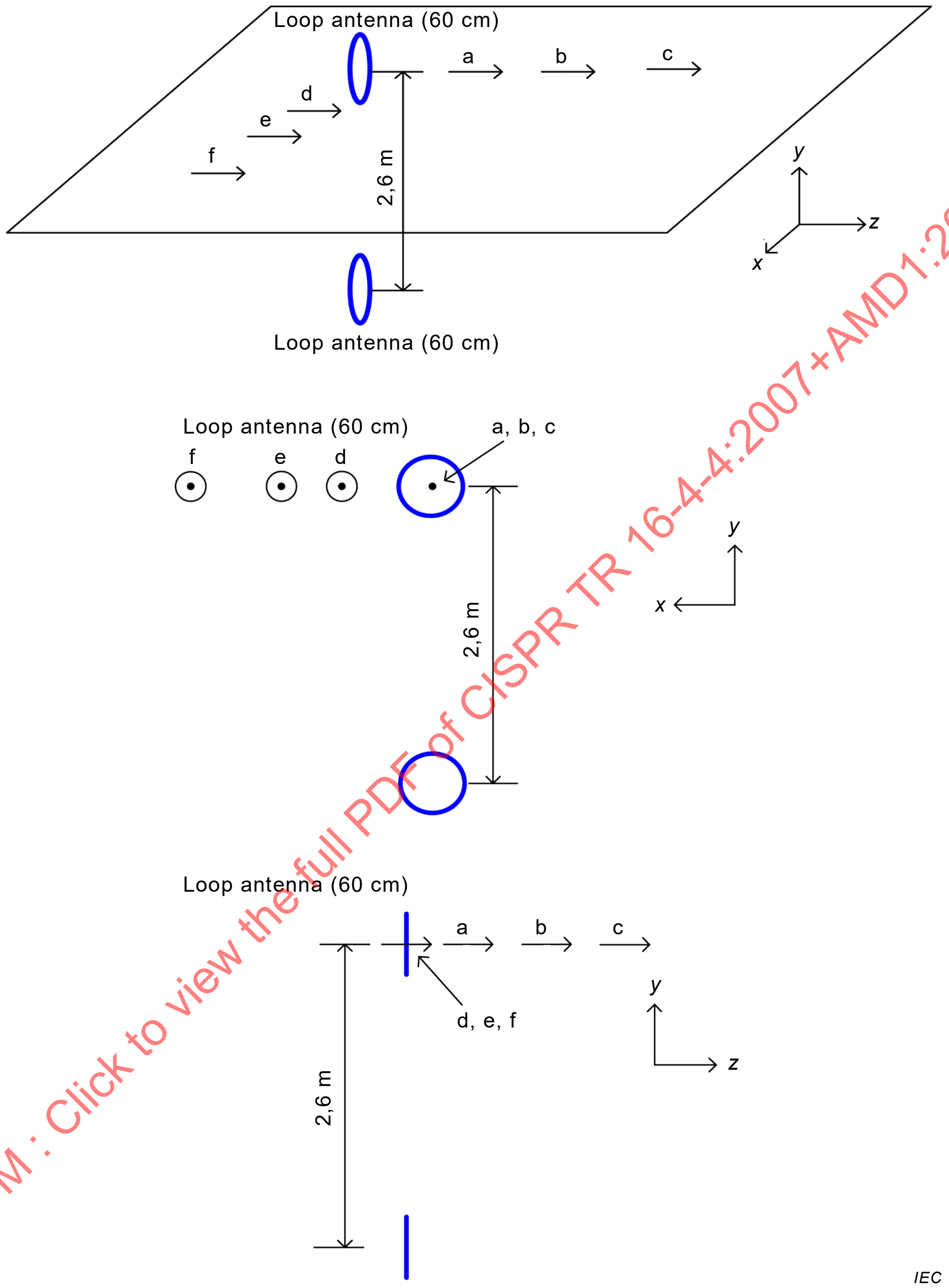

Figure B.2 – Commercial tool model for the application of image theory

Figure B.3 shows the scene of OATS where measurement is carried out at 1,3 m height from the centre of the antenna with 3 m distance between antennas at coaxial and coplanar direction, respectively.

a) **Measurement at coaxial direction at 3 m**

b) **Measurement at coplanar direction at 3 m**

Figure B.3 – Photos of OATS measurement setup

Figure B.4 is a graphical presentation which allows us to compare the results from a simulation both at coaxial and coplanar directions where the ground plane using a commercial tool is included and where image theory has been applied. It suggests that the simulation result from each model almost agrees.

Figure B.5 presents comparison results between the H-field conversion factors determined by using commercial tools and measurement data.

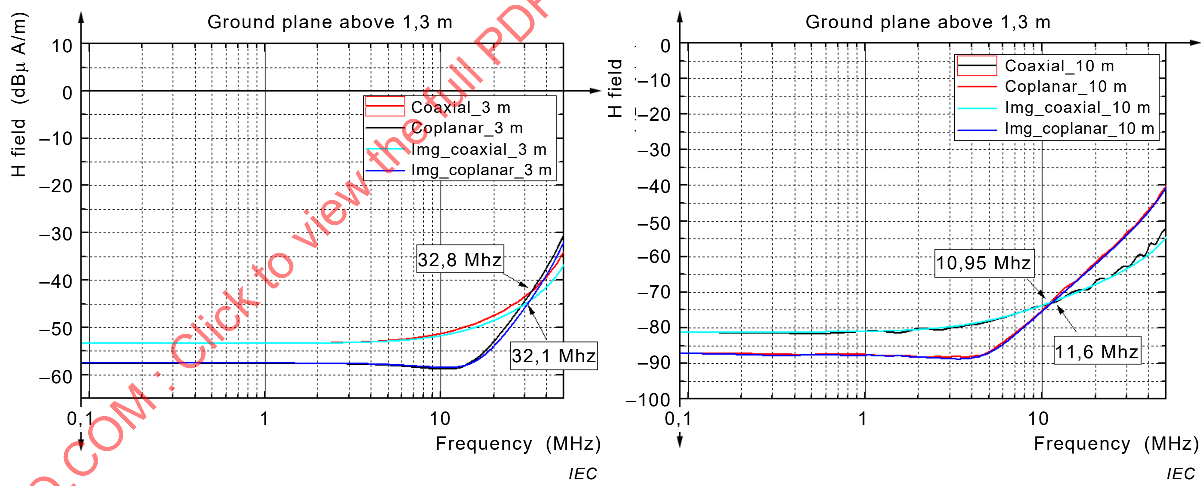

Figure B.4 – Comparative simulation result with ground plane and with image theory

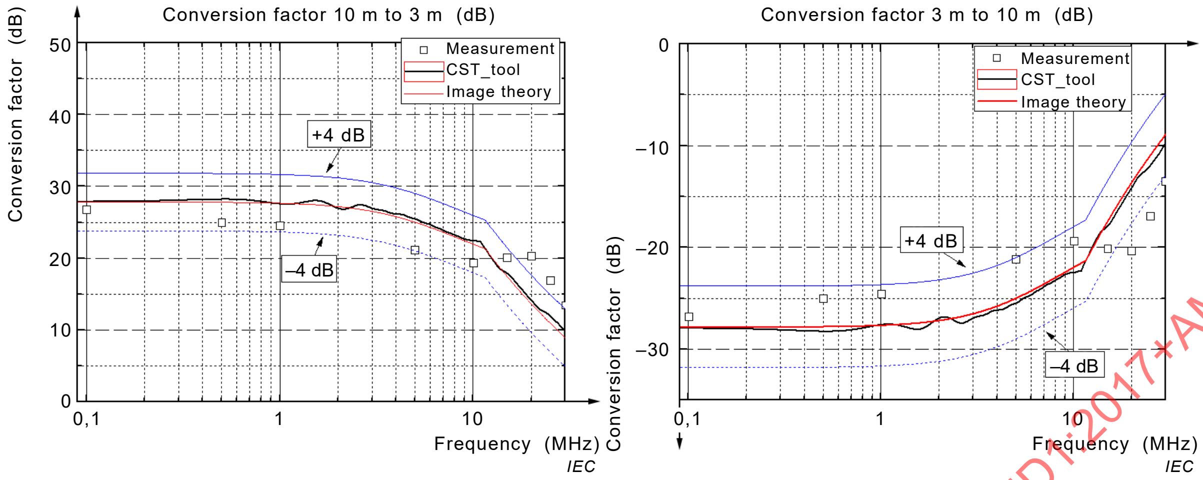

Figure B.5 – Comparison between the simulated conversion factors and the measurement results

B.2 H-field conversion factors obtained from simulation results

The conversion factors of measurement distances of 3 m and 10 m are derived from the measurement distance of 30 m under the test environment with the ground plane for H-field measurement.

The H-field limit in dBμA/m at 3 m, H_{3m}, is determined from H_{30m} by the following equation:

$$H_{3m} = H_{30m} + C_{3\_min} \qquad \text{(B.1)}$$

where

H_{30m} is the H-field limit in dBμA/m at 30 m distance;

C_{3_min} is a conversion factor in dB as shown in Figure B.6 and Table B.1

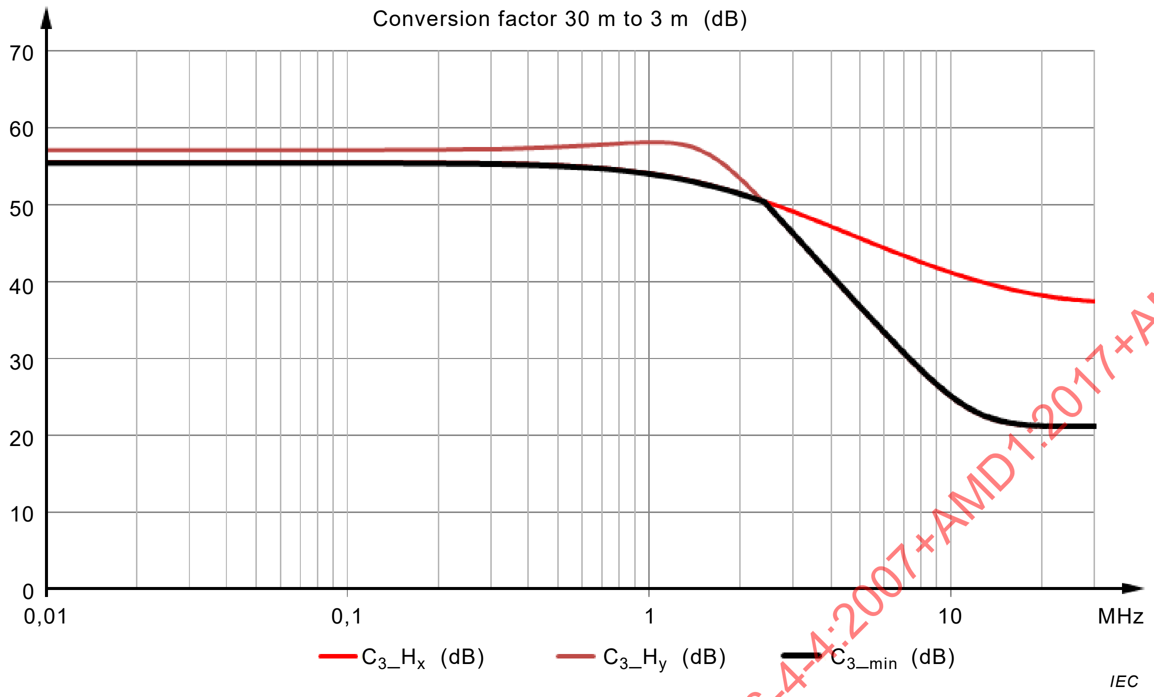

Figure B.6 – Conversion factor C_{3_min}

Table B.1 – Conversion factor C_{3_min}

Frequency MHz	$C_3\_H_x$ dB	$C_3\_H_y$ dB	C_{3_min} dB
0,01 (or 0,009)	55,3	57,2	55,3
0,15	55,5	57,3	55,5
1	54,1	58,2	54,1
2	51,5	53,6	51,5
2,4	50,5	50,5	50,5
3	49,1	46,3	46,3
5	45,7	36,7	36,7
10	41,2	25,1	25,1
11	40,7	23,9	23,9
12	40,3	23,0	23,0
13	39,9	22,4	22,4
14	39,5	22,0	22,0
15	39,3	21,7	21,7
20	38,3	21,2	21,2
30	37,5	21,1	21,1

The H-field limit in dBµA/m at 10 m, H_{10m}, is determined from H_{30m} by the following equation:

$$H_{10m} = H_{30m} + C_{10\_min} \quad (B.2)$$

where

H_{30m} is the H-field limit in dBµA/m at 30 m distance;

C_{10_min} is a conversion factor in dB as shown in Figure B.7 and Table B.2.

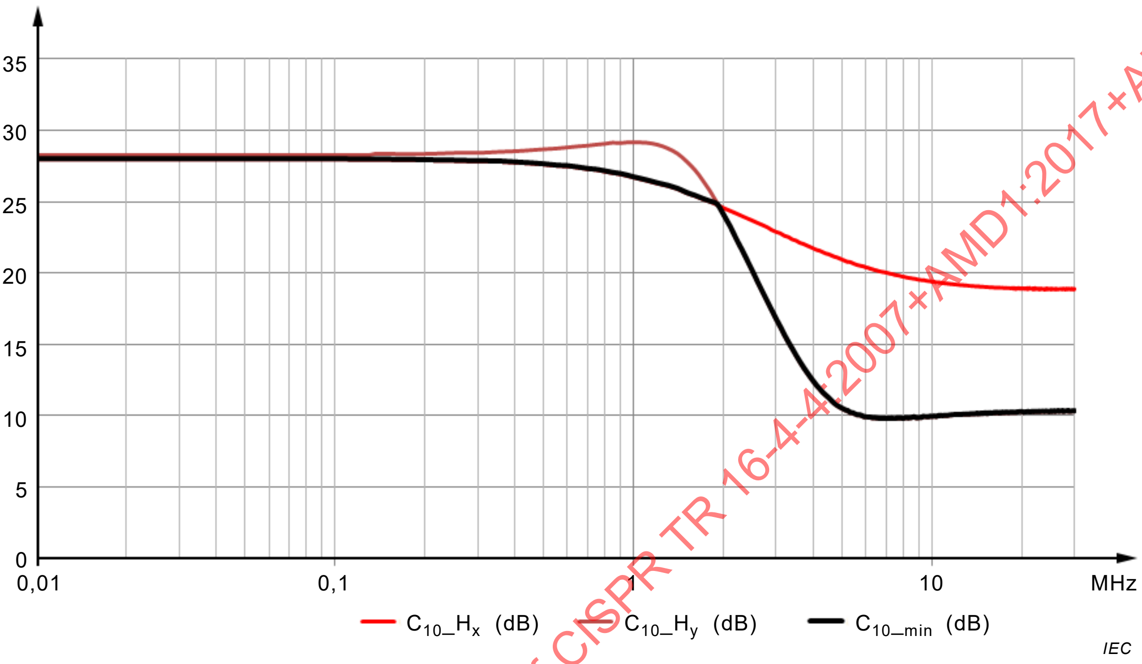

Figure B.7 – Conversion factor C_{10_min}

Table B.2 – Conversion factor C_{10_min}

Frequency MHz	C_{10}–H_x dB	C_{10}–H_y dB	C_{10_min} dB
0,01 (or 0,009)	28,0	28,3	28,0
0,10	28,0	28,3	28,0
0,15	28,0	28,3	28,0
0,2	27,9	28,3	27,9
0,3	27,9	28,4	27,9
0,4	27,8	28,5	27,8
0,5	27,7	28,7	27,7
0,6	27,5	28,8	27,5
0,7	27,3	28,9	27,3
0,8	27,2	29,0	27,2
0,9	27,0	29,1	27,0
1	26,7	29,1	26,7
1,9	24,8	24,9	24,8
2	24,6	24,1	24,1
3	22,9	16,7	16,7
5	21,0	10,5	10,5
10	19,4	9,9	9,9
20	19,0	10,3	10,3
30	18,9	10,3	10,3

The H-field limit in dBµA/m at 3 m, H_{3m}, can be also determined from H_{10m} by the following equation:

$$H_{3m} = H_{10m} + C_{10\text{-}3\_min} \qquad \text{(B.3)}$$

where

H_{10m} is the H-field limit in dBµA/m at 10 m distance;

$C_{10\text{-}3\_min}$ is a conversion factor in dB as shown in Figure B.8 and Table B.3.

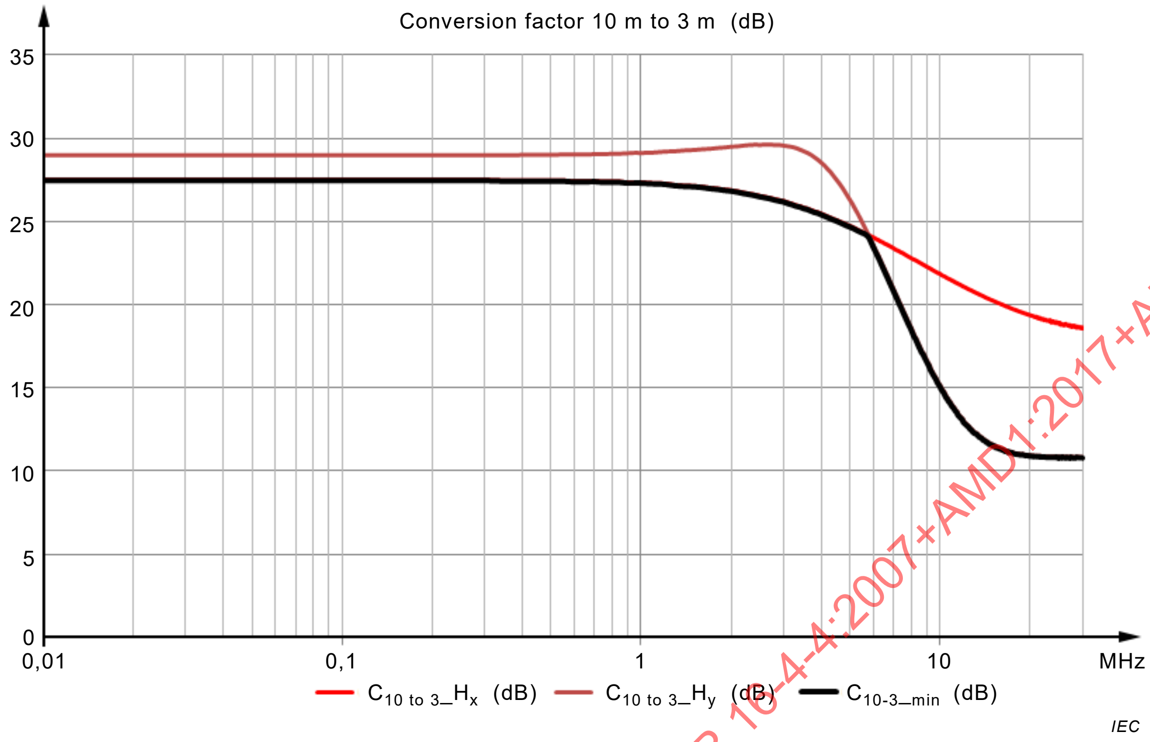

Figure B.8 – Conversion factor $C_{10\text{-}3\_min}$