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Edition 2.1 2017-06

CONSOLIDATED VERSION

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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 CSV(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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This Consolidated version of CISPR 16-4-4 bears the edition number 2.1. It consists of the second edition (2007-070) [documents CISPR/H/147/DTR and CISPR/H/153/RVC] and its amendment 1 (2017-06) [documents CIS/H/313/DTR and CIS/H/319/RVC]. The technical content is identical to the base edition and its amendment.

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. 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 amendment 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.

A bilingual version of this publication may be issued at a later date.

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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 – Chapter 161: Electromagnetic compatibility*

CISPR 11, *Industrial, scientific and medical (ISM) radio-frequency equipment – Electromagnetic 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*

3 Terms and definitions

For the purposes of this document, the terms and definitions in IEC 60050(161) as well as the following apply.

3.1
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)

3.2
RFI investigation service
institution having the task of investigating reported cases of radio frequency interference and which operates at the national basis

NOTE Examples include a radio service provider, a CATV network provider, an administration, or a regulatory authority.

3.3
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

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

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
I	**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 $P(B|A) \approx 1$. 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.

$P(D|A \text{ and } C)$ 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 $P(D|A \text{ and } C) \leq P(B|A)$; 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.

$P(A \text{ and } C)$ 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, $P(A \text{ and } C) = P(A)P(C)$, 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 $P(A \text{ and } C)$ 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, $P(A \text{ and } C) = 1$, 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.

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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.

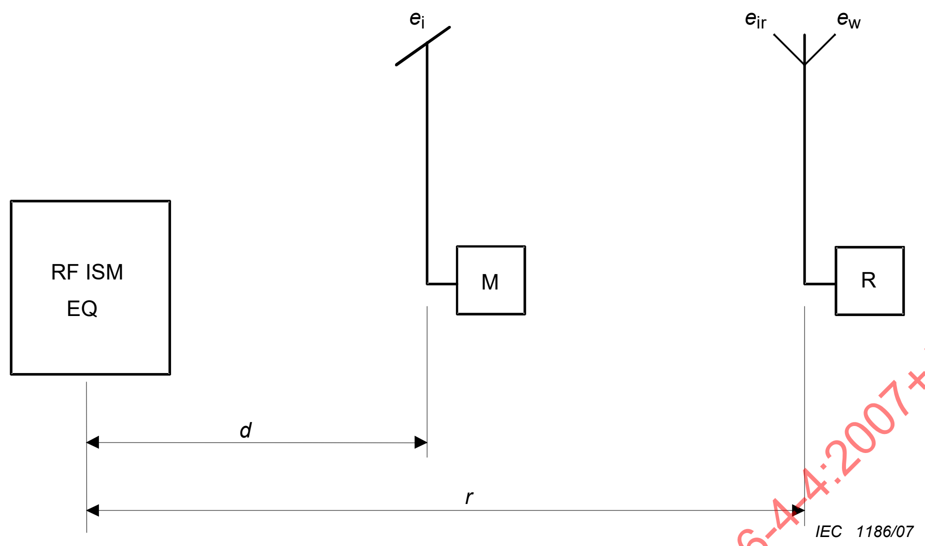
For critical or safety related radio services, however, a much higher degree of confidence is necessary. The actual annoyance in an interfered radio service does not only depend on the RFI field strength, but on the wanted signal level as well. The ratio of wanted-to-unwanted input level which procures 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.

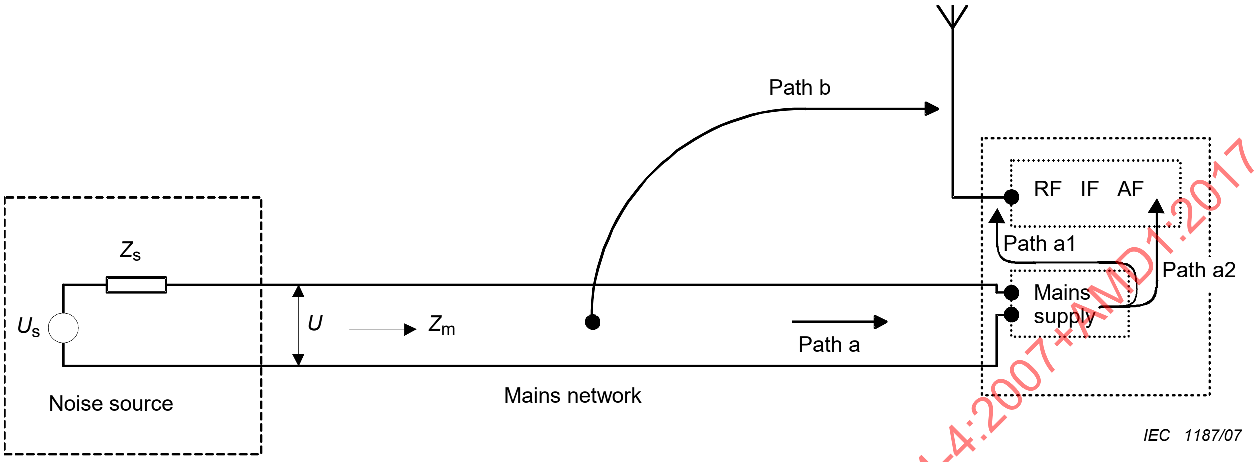


Figure 3 – Model for close coupling situations

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:

$$\mu_x = \mu_y + t_\alpha \sigma_z \tag{8}$$

$$\mu_y = \mu_x - t_\alpha \sigma_z \tag{9}$$

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:

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

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

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)

$$L_x = \mu_y + t_\alpha \sigma_z - t_\beta \sigma_x \tag{12}$$

$$L_y = \mu_x - t_\alpha \sigma_z + t_\beta \sigma_y \tag{13}$$

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

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

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

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

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:

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

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:

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

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:

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

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_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

$$\mu_{ir}/\text{dB}(\mu\text{V/m}) = 20\lg(7/d)/\text{dB}(\Omega^{1/2}/\text{m}) + \mu_u/\text{dB}(\mu\text{V}) - 0{,}5\mu_z/\text{dB}(\Omega^{1/2}) - \mu_a/\text{dB}$$

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.

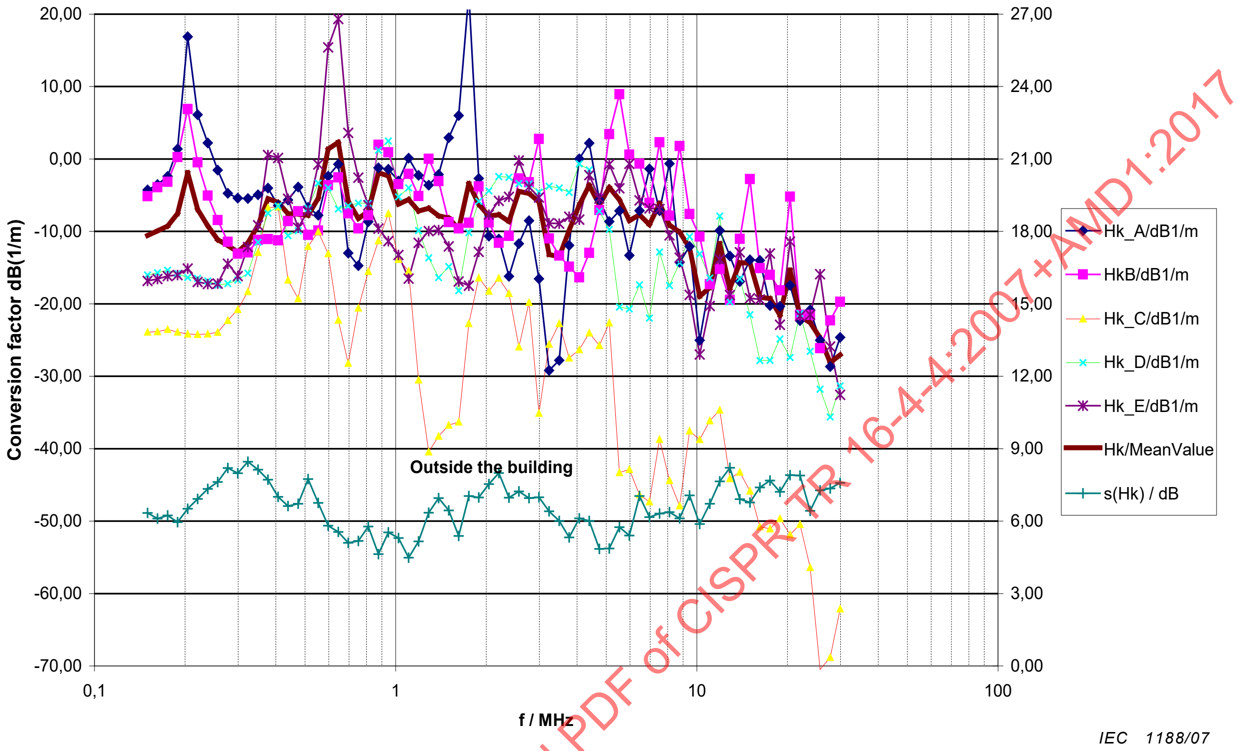


Figure 4 – Example of conversion factors – field strength / common-mode voltage (in dB) – at feed point, found in practice

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).

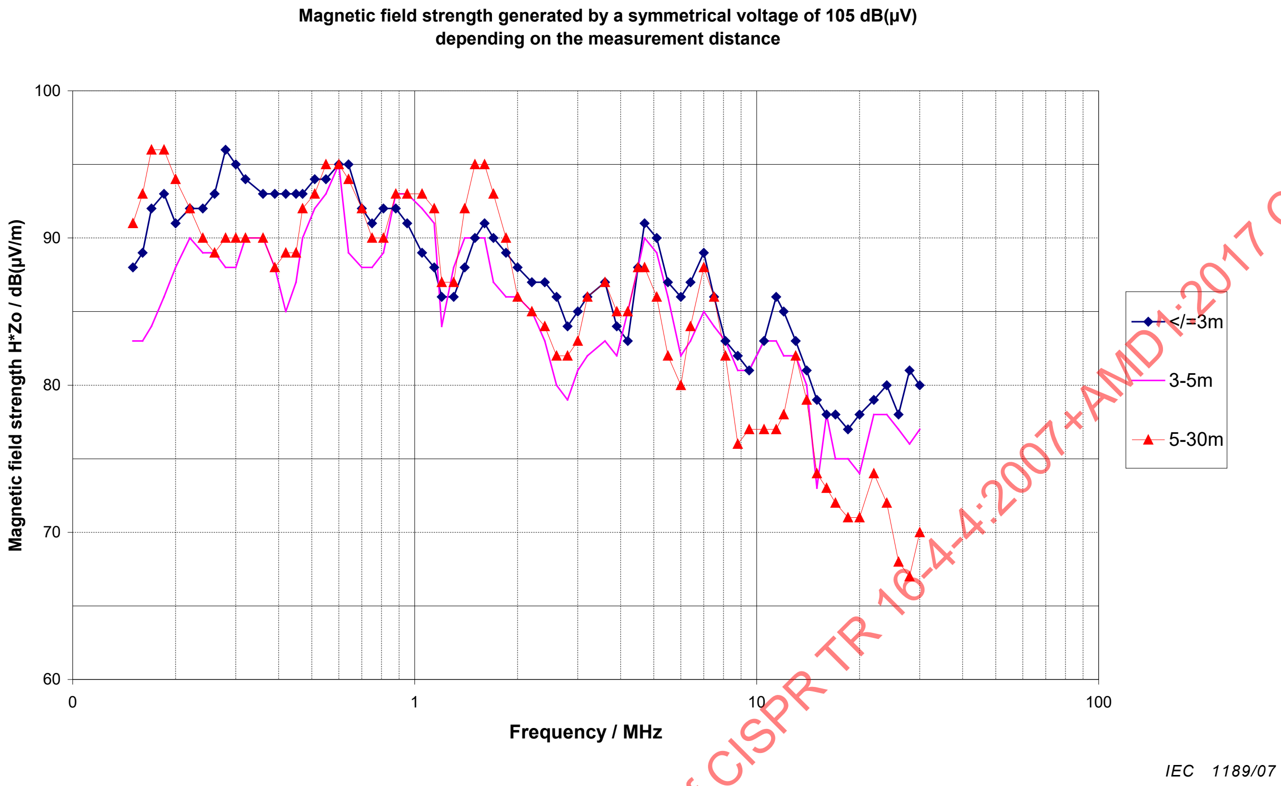


Figure 5 – Example of conversion factors – field strength generated by differential-mode voltage – at feed point, found in practice

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.)

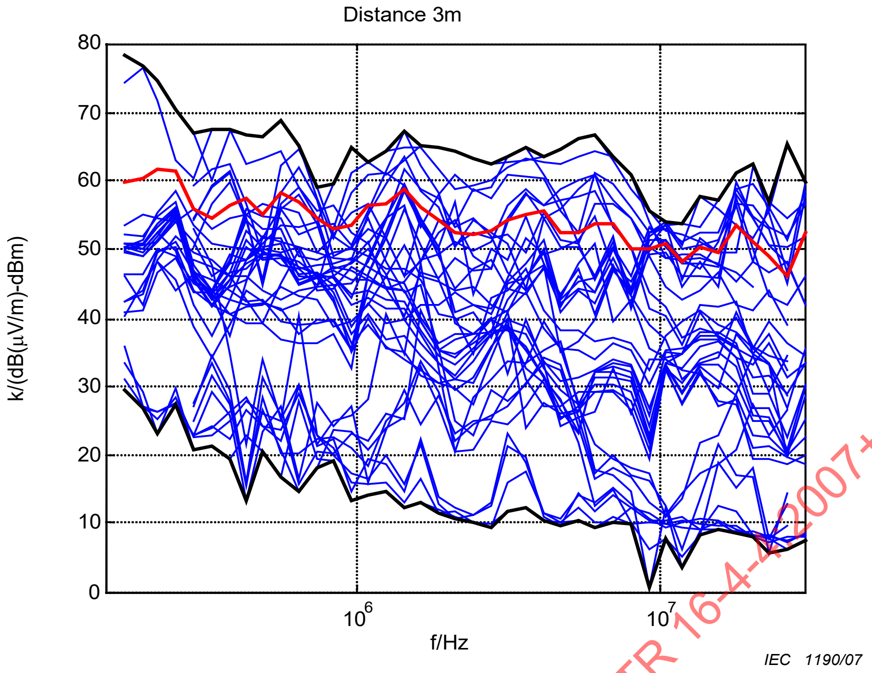


Figure 6 – Example of conversion factors – field strength generated by differential-mode voltage – outside buildings and electrical substations, found in practice

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.

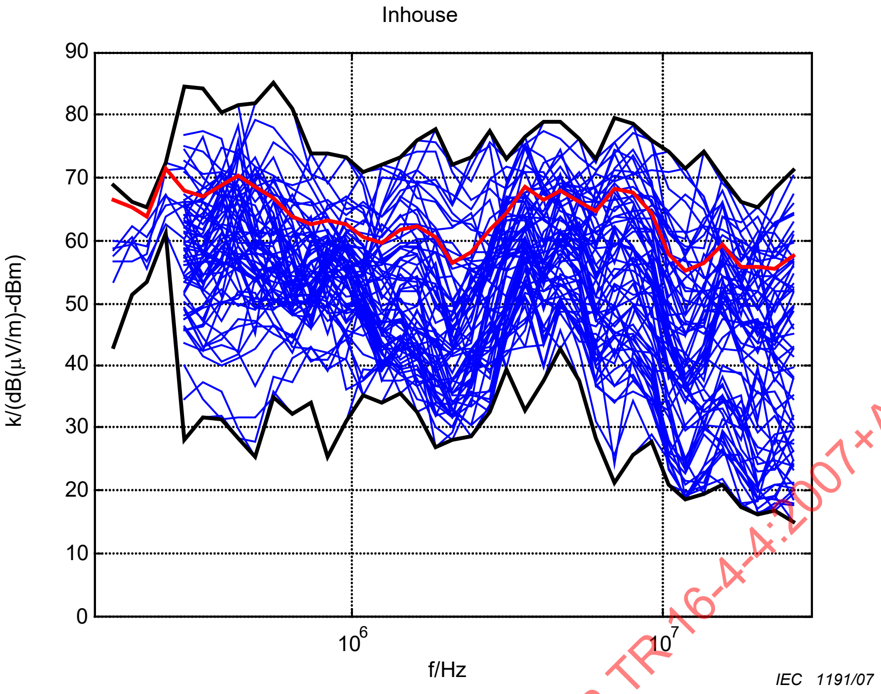


Figure 7 – Example of conversion factors – field strength generated by differential-mode voltage – inside buildings, found in practice

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(μV/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(μV/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(μV/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(μV/m)	Corresponding limit at 30 m from boundary dB(μV/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(μV/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(µV/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(µV/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(µV/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(µV/m)	Corresponding limit at 30 m from boundary dB(µV/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(µV/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(µV/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(µV/m)	Distance from equipment at which signal is to be protected m	Attenuation law	Approximate equivalent interference field at 20 m from equipment dB(µv/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(µV/m)	Corresponding limit at 30 m from boundary dB(µV/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(µv/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

$$E_{\mathrm{Limit}} = \mu_{\mathrm{i}} + t_{\beta}\sigma_{\mathrm{i}} \tag{36}$$

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

$$E_{\mathrm{Limit}} = \mu_{\mathrm{w}} - R_{\mathrm{p}} + \mu_{\mathrm{P1}} + \mu_{\mathrm{P2}} + \mu_{\mathrm{P3}} + \mu_{\mathrm{P4}} + \mu_{\mathrm{P5}} + \mu_{\mathrm{P6}} + \mu_{\mathrm{P7}} + \mu_{\mathrm{P8}} + \mu_{\mathrm{P9}} + \mu_{\mathrm{P10}}$$

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

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

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

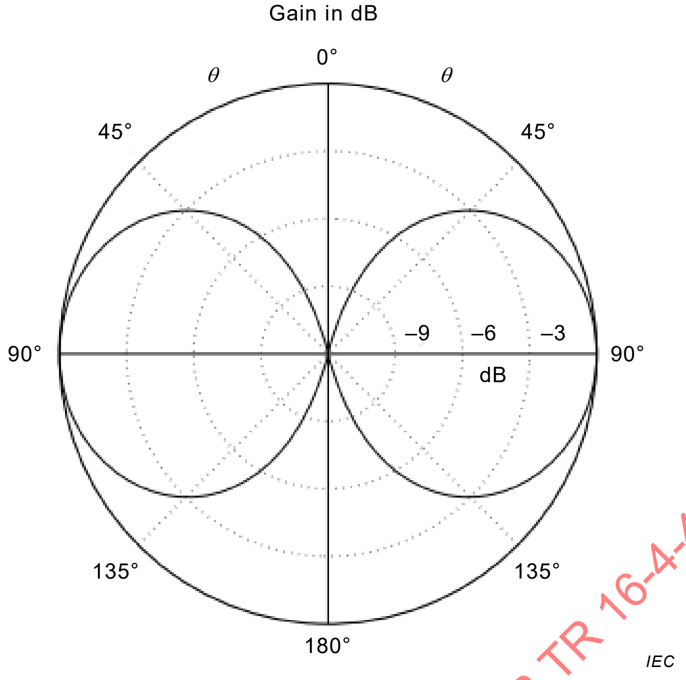


Figure 8 – horizontal plane radiation pattern on a small purely magnetic antenna

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.

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

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

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.

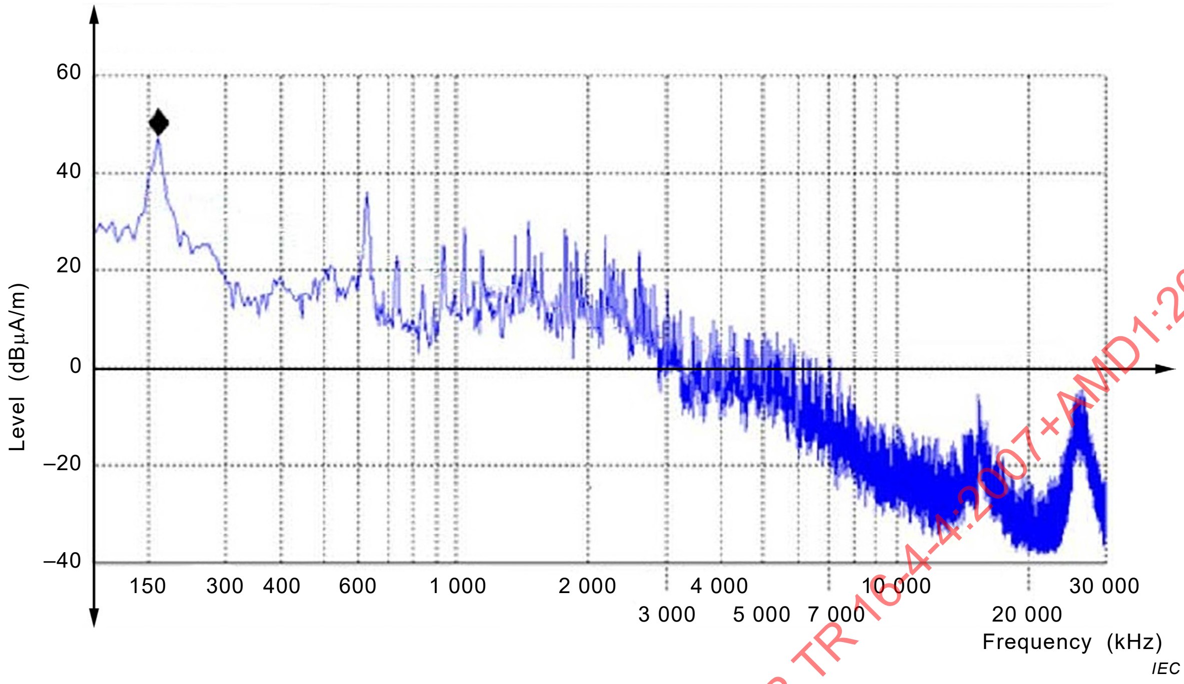


Figure 9 – typical source of magnetic field disturbance

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:

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

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}

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

5.6.6 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

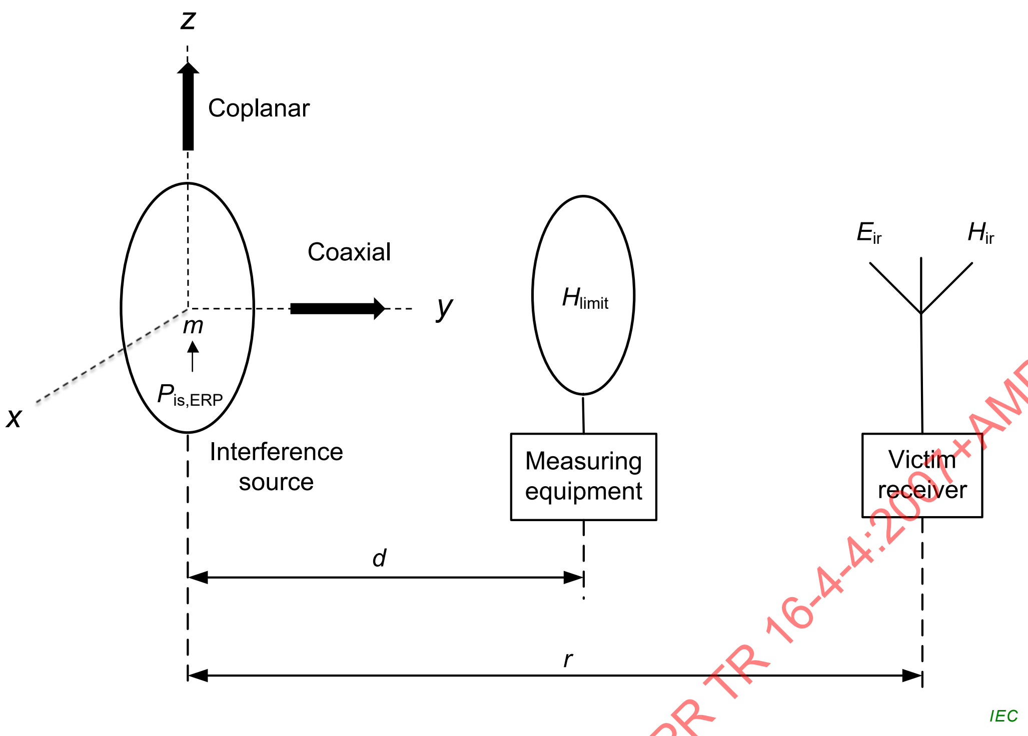
Recently, new electric or electronic devices having unintentional emissions below 30 MHz were introduced in the market. As the classical examples of these devices, there are plasma TV sets, power line communications devices, wireless power transfer, induction cooking devices, and so on. As the devices 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:

$$E_{\text{Limit}}\ [\text{dB}(\mu\text{V/m})] = 104{,}8\ \text{dB} + P_{\text{limit}}\ [\text{dB(mW)}] + G_{\text{S}}\ [\text{dB}] - 20\ \lg\left(d/d_{\text{Ref})\ [\text{dB})]}\right) \qquad (36a)$$

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

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

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

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

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:

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

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:

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

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:

$$\mu_{P3} \text{ ranges from } 0 \text{ dB to } 9 \text{ dB.}$$

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:

$$\mu_{P4} \text{ ranges from } 0 \text{ dB to } 24 \text{ dB.}$$

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:

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

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%.

References

i) S. Whitehead: *A tentative statistical study of domestic radio interference*. Journal IEE, p. III., vol. 90 - 1943.

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).

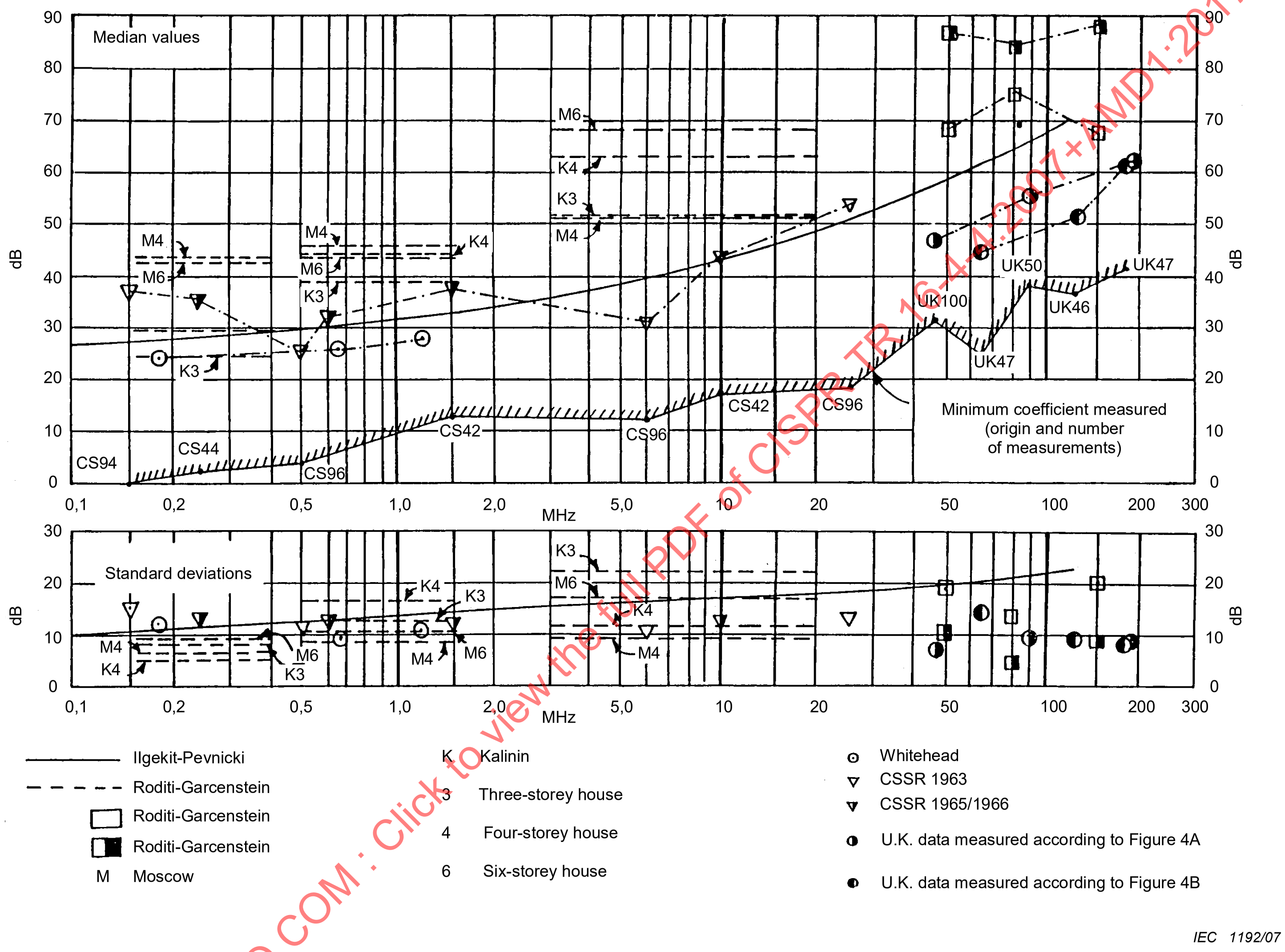


Figure A.1 – Mains decoupling coefficient as measured by various authors

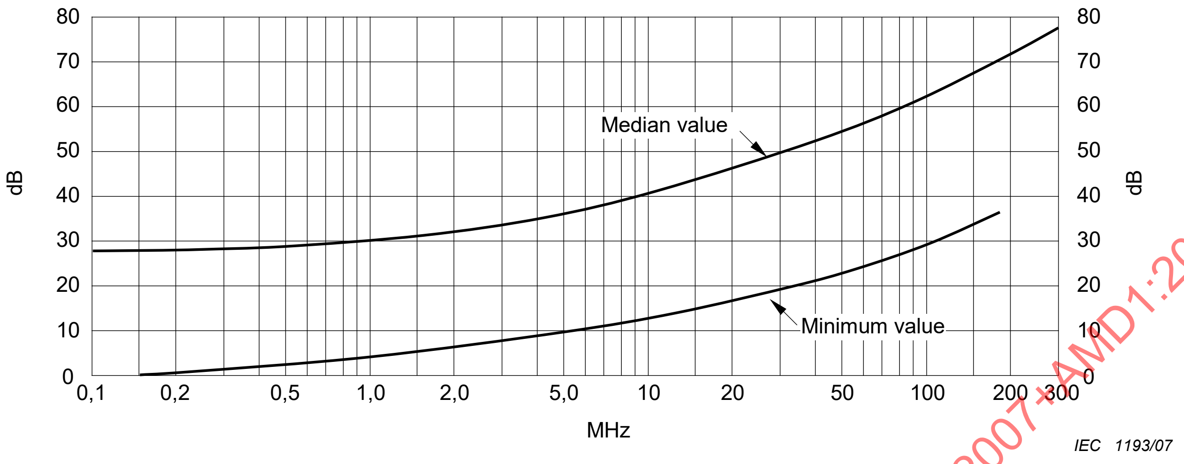


Figure A.2 – Median and minimum values of mains decoupling factor for the range 0,1 MHz to 200 MHz

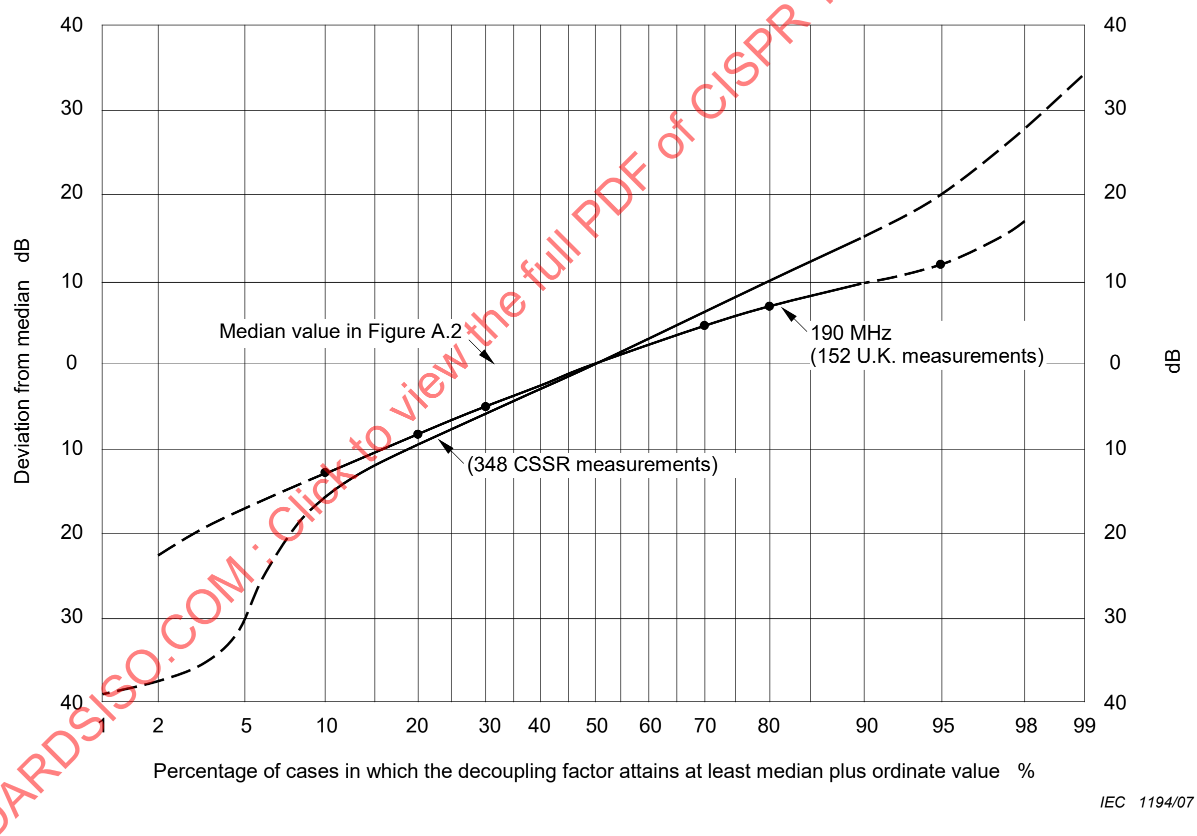


Figure A.3 – Typical distributions of deviations from median value of decoupling factor as indicated in Figure A.2

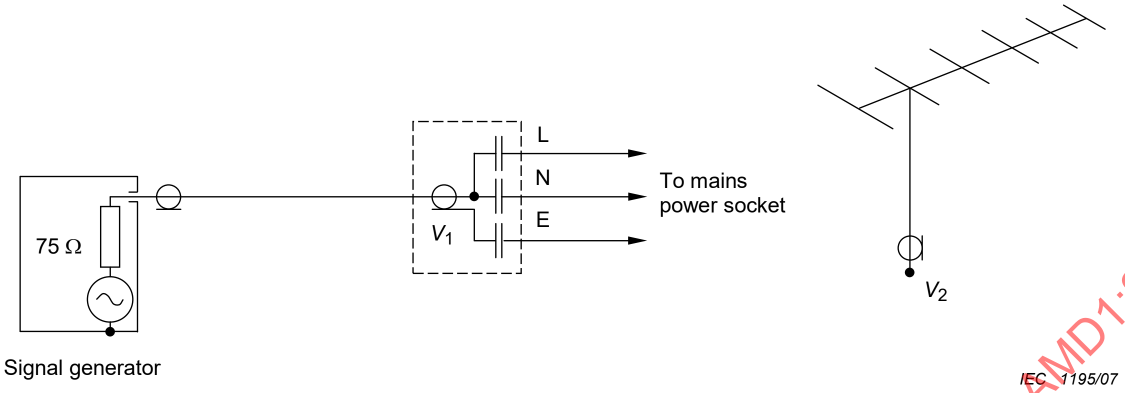


Figure A – Measurement with signal generator

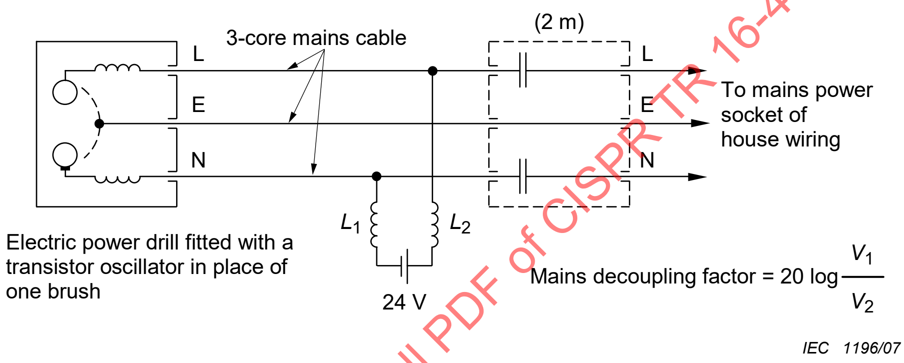


Figure B – Measurement using actual appliance

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).

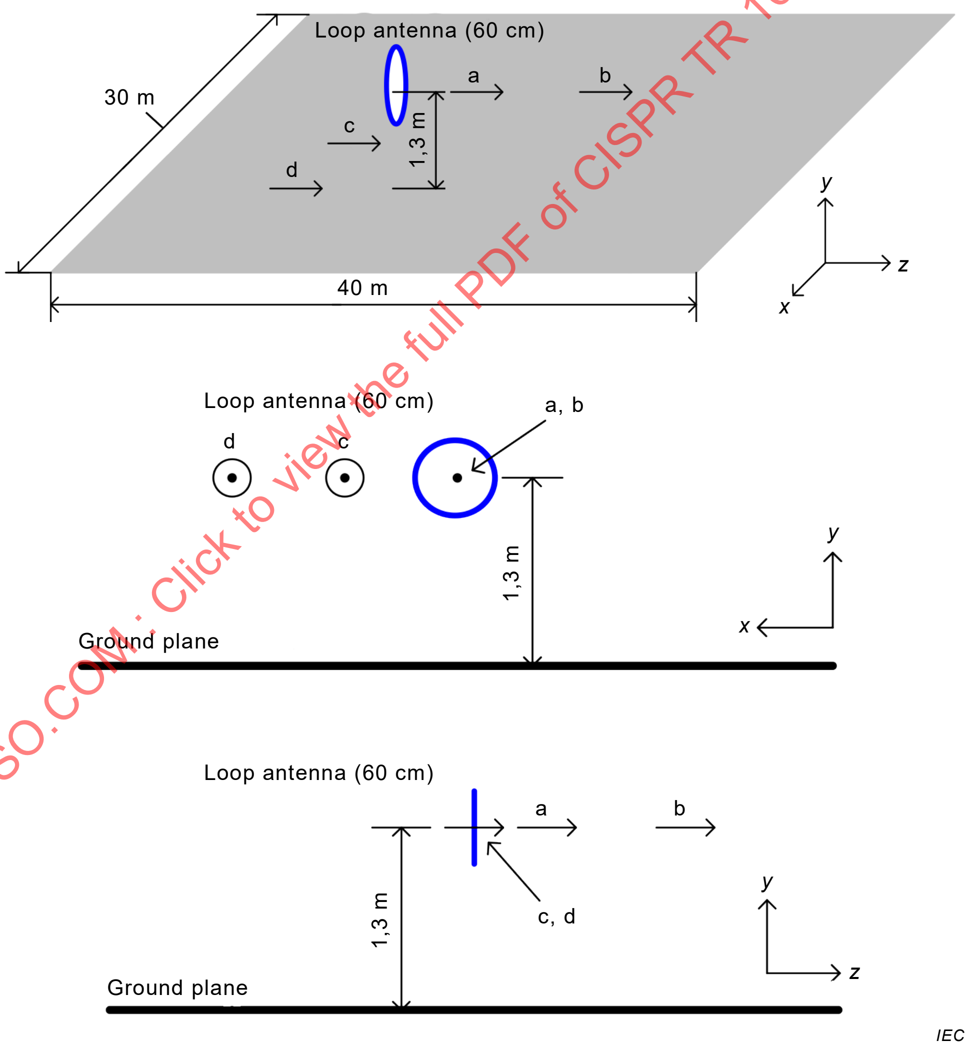


Figure B.1 – Commercial tool model for H-field conversion

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.

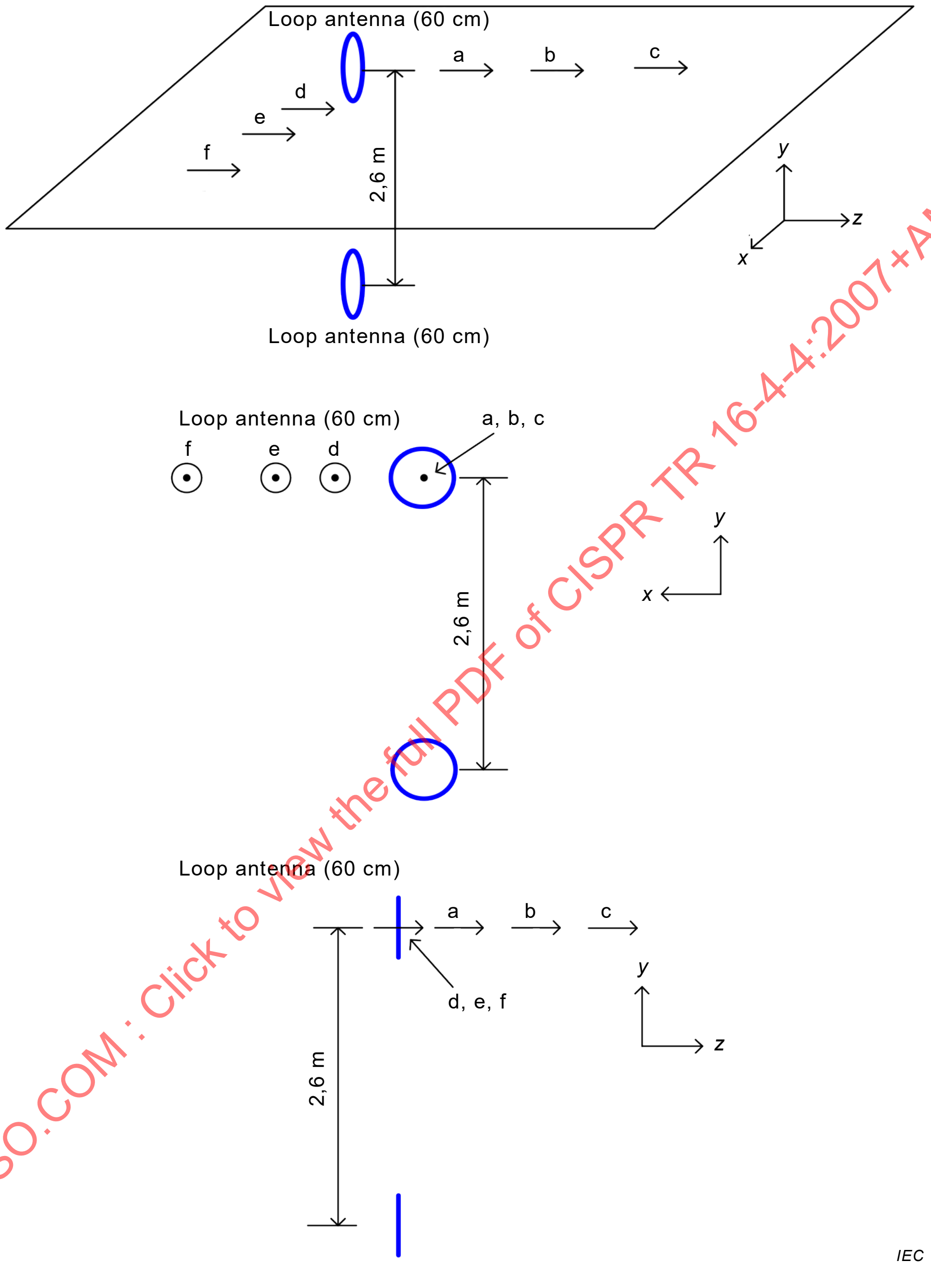


Figure B.2 – Commercial tool model for the application of image theory

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.

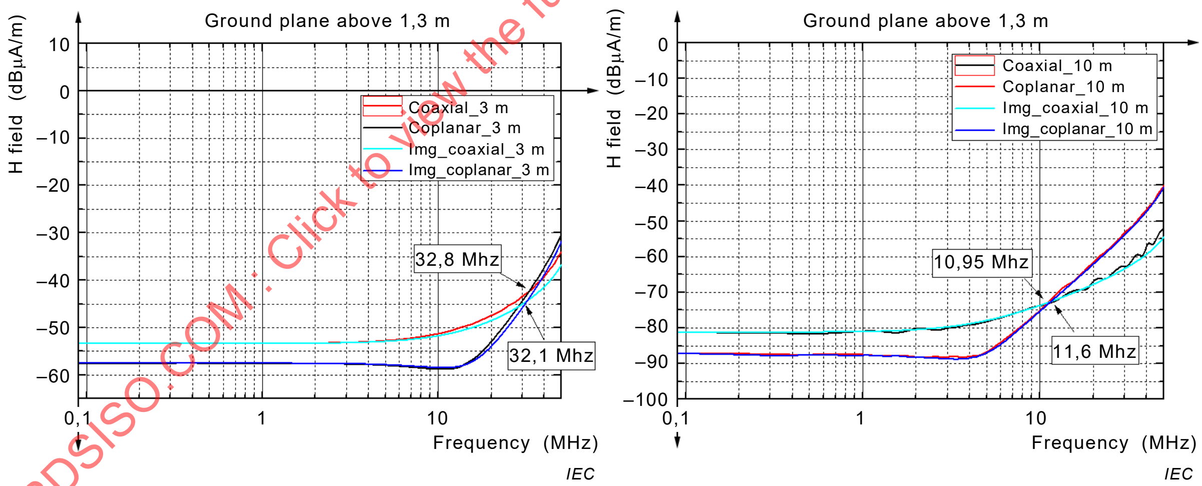


Figure B.4 – Comparative simulation result with ground plane and with image theory

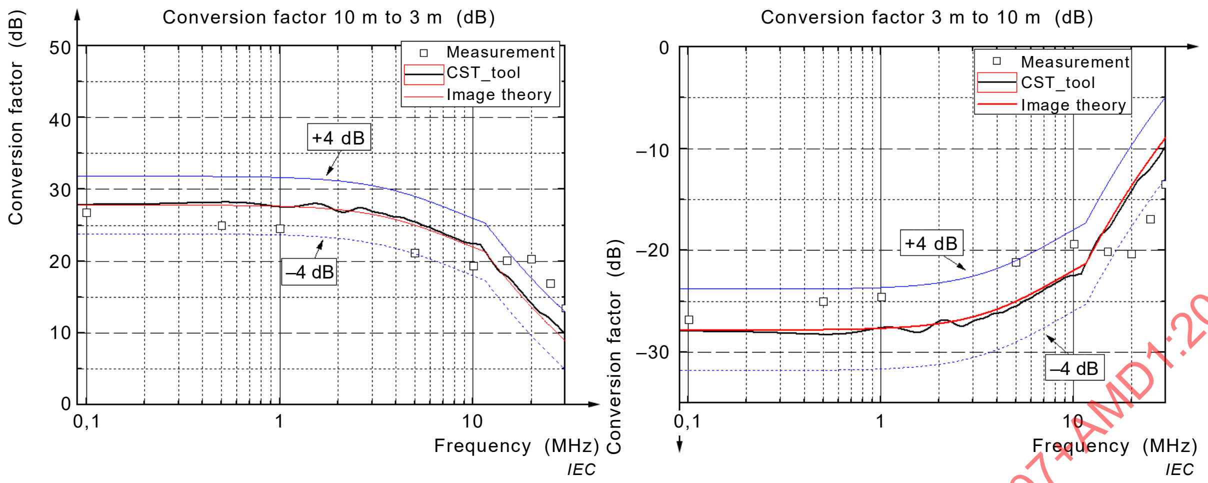


Figure B.5 – Comparison between the simulated conversion factors and the measurement results

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:

$$H_{3m} = H_{30m} + C_{3\_min} \tag{B.1}$$

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

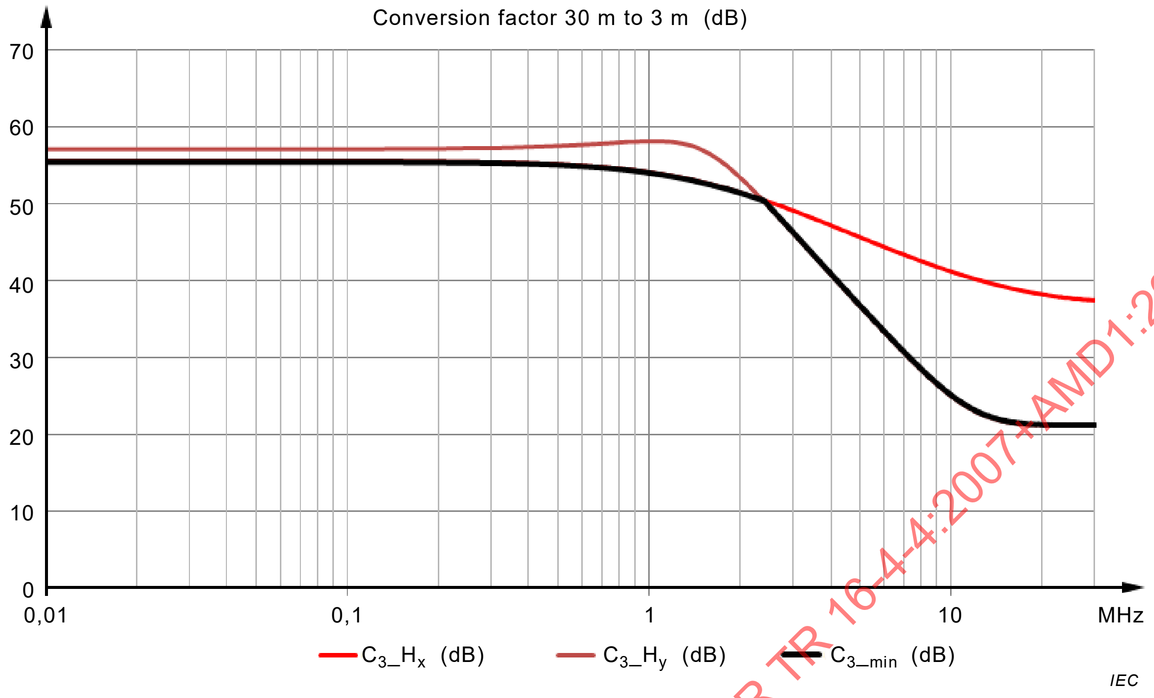


Figure B.6 – Conversion factor C_{3_min}

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:

$$H_{10m} = H_{30m} + C_{10\_min} \tag{B.2}$$

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.

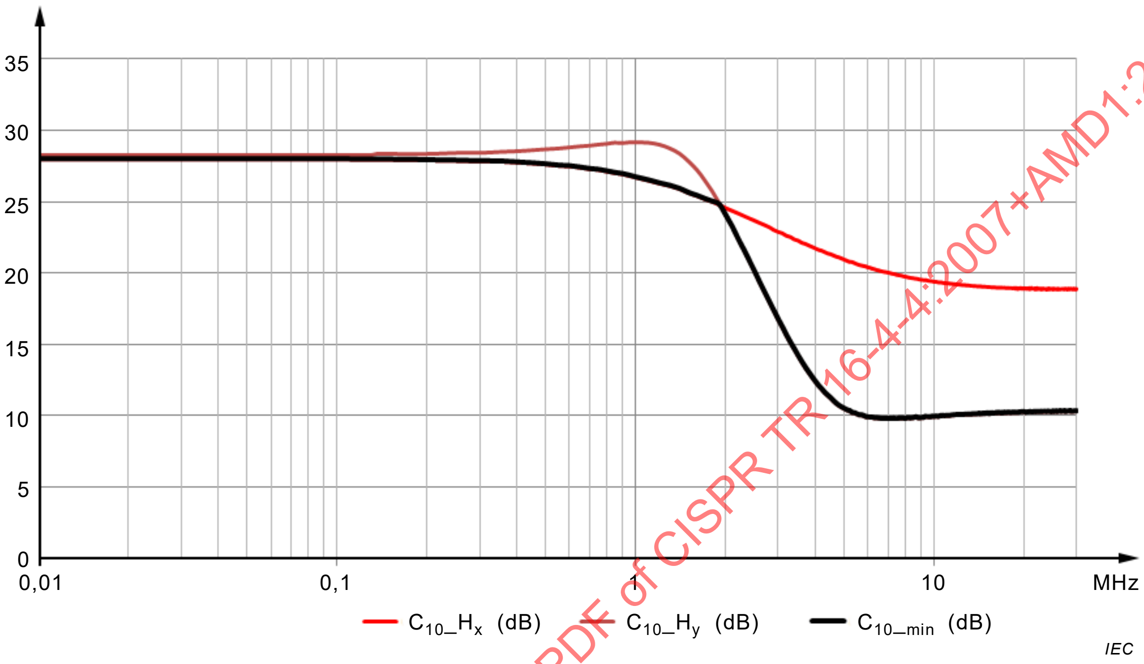


Figure B.7 – Conversion factor C_{10_min}

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:

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

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.

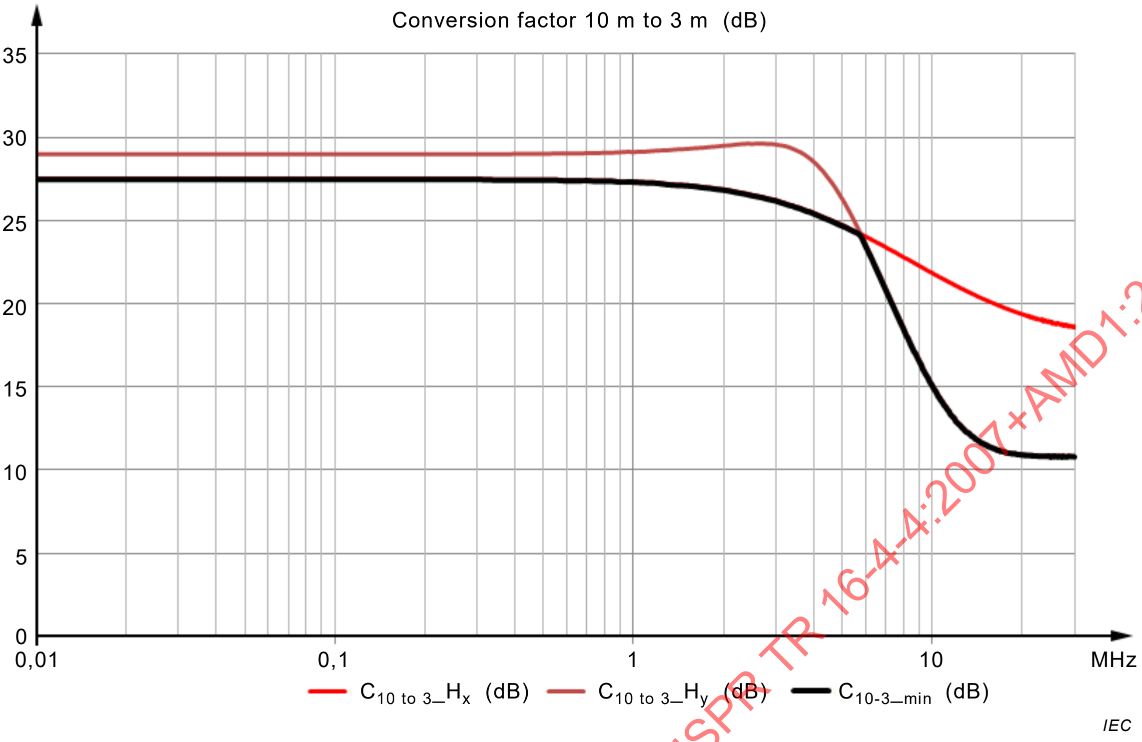


Figure B.8 – Conversion factor $C_{10\text{-}3\_min}$

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

Frequency MHz	$C_{10\ to\ 3\_H_x}$ dB	$C_{10\ to\ 3\_H_y}$ 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, $CF_{30m\ to\ 3m}$

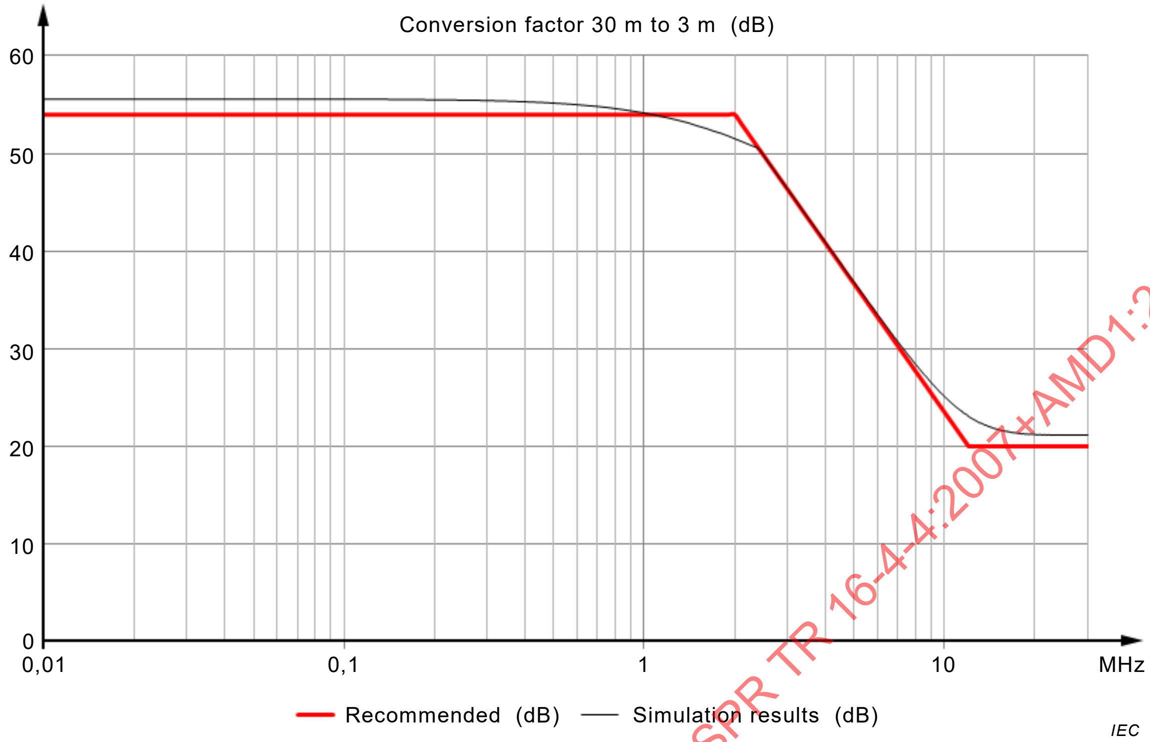


Figure B.9 – Recommended conversion factor $CF_{30m\ to\ 3m}$

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, $CF_{30m\ to\ 10m}$

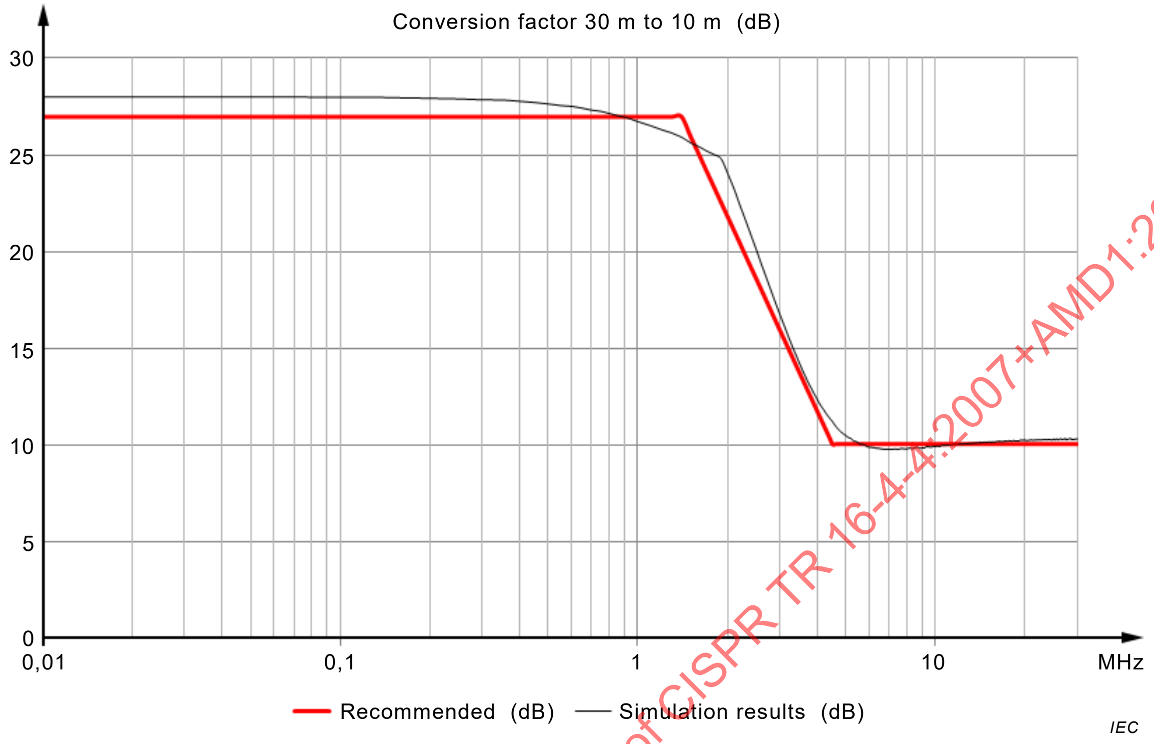


Figure B.10 – Recommended conversion factor $CF_{30m\ to\ 10m}$

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, $CF_{10m\ to\ 3m}$

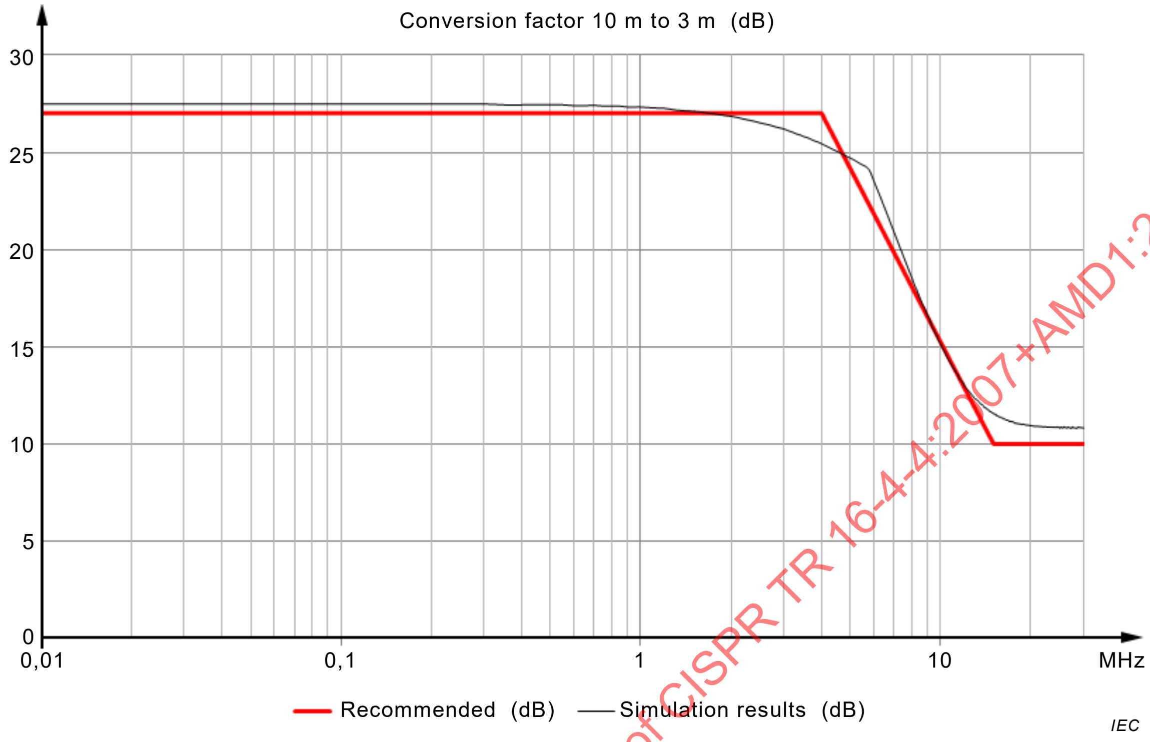


Figure B.11 – Recommended conversion factor $CF_{10m\ to\ 3m}$

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

Bibliography

The references listed hereafter contain literature and further detailed information to the subjects dealt with in the context of this edition of CISPR 16-4-4 and are recommended for further consideration.

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[9] IEC 61000-6-3, *Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments*

[10] IEC 61000-6-4, *Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments*

[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, *Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment*

[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*

[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 2.1 2017-06

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 CSV(en)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

FOREWORD

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DISCLAIMER
This Consolidated version is not an official IEC Standard and has been prepared for user convenience. Only the current versions of the standard and its amendment(s) are to be considered the official documents.

This Consolidated version of CISPR 16-4-4 bears the edition number 2.1. It consists of the second edition (2007-070) [documents CISPR/H/147/DTR and CISPR/H/153/RVC] and its amendment 1 (2017-06) [documents CIS/H/313/DTR and CIS/H/319/RVC]. The technical content is identical to the base edition and its amendment.

This Final version does not show where the technical content is modified by amendment 1. 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 amendment 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.

A bilingual version of this publication may be issued at a later date.

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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 – Chapter 161: Electromagnetic compatibility*

CISPR 11, *Industrial, scientific and medical (ISM) radio-frequency equipment – Electromagnetic 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*

3 Terms and definitions

For the purposes of this document, the terms and definitions in IEC 60050(161) as well as the following apply.

3.1
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)

3.2
RFI investigation service
institution having the task of investigating reported cases of radio frequency interference and which operates at the national basis

NOTE Examples include a radio service provider, a CATV network provider, an administration, or a regulatory authority.

3.3
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

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

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
I	**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

$$P(\mathrm{I}) = P(\mathrm{A\ and\ B\ and\ C\ and\ D^*}) \qquad (1)$$

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

$$P(\mathrm{I}) = [P(\mathrm{B}|\mathrm{A}) - P(\mathrm{D}|\mathrm{A\ and\ C})]\ P(\mathrm{A\ and\ C}) \qquad (2)$$

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

$$P'(\mathrm{I}) = P(\mathrm{B\ and\ C\ and\ D^*}|\mathrm{A}) \qquad (3)$$

which can be reduced to:

$$P'(\mathrm{I}) = [P(\mathrm{B}|\mathrm{A}) - P(\mathrm{D}|\mathrm{A\ and\ C})]\ P(\mathrm{C}|\mathrm{A}) \qquad (4)$$

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 $P(\mathrm{B}|\mathrm{A}) \approx 1$. In other services, such as long-distance ionospheric point-to-point services, or mobile services near the edge of the coverage area, $P(\mathrm{B}|\mathrm{A})$ may be quite small. In this latter case, the probability of interference will not be small regardless of the other probabilities.

$P(\mathrm{D}|\mathrm{A}$ 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 $P(\mathrm{D}|\mathrm{A}$ and C) ≤ $P(\mathrm{B}|\mathrm{A})$; 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 $P(\mathrm{I})$ 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) = $P(\mathrm{A})P(\mathrm{C})$, where $P(\mathrm{A})$ is the fraction of time that the wanted transmitter is emitting, and $P(\mathrm{C})$ 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, $P(\mathrm{C}|\mathrm{A}) = P(\mathrm{C})$ if the transmitters operate independently. $P(\mathrm{C}|\mathrm{A})$ is very small if the two transmitters are co-channel stations in a disciplined land mobile service; and $P(\mathrm{C}|\mathrm{A}) = 1$ 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.

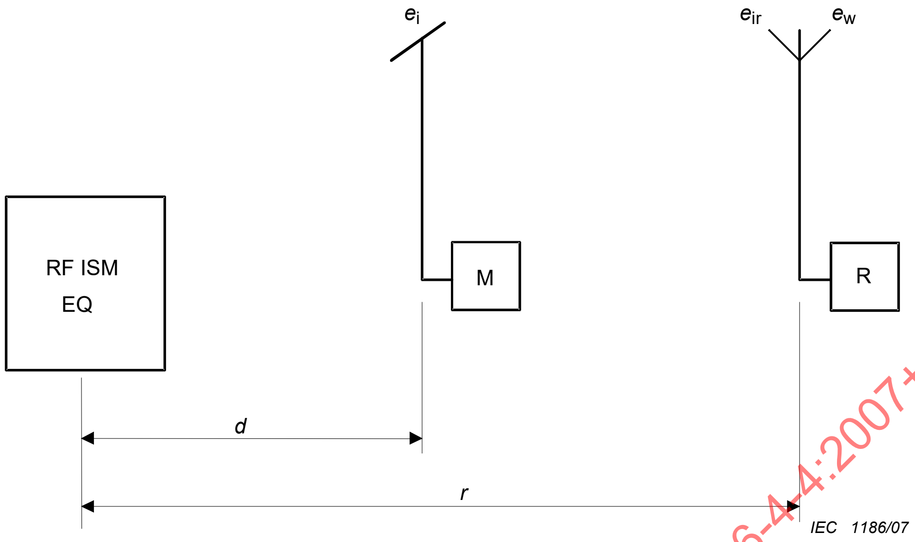
For critical or safety related radio services, however, a much higher degree of confidence is necessary. The actual annoyance in an interfered radio service does not only depend on the RFI field strength, but on the wanted signal level as well. The ratio of wanted-to-unwanted input level which procures 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.

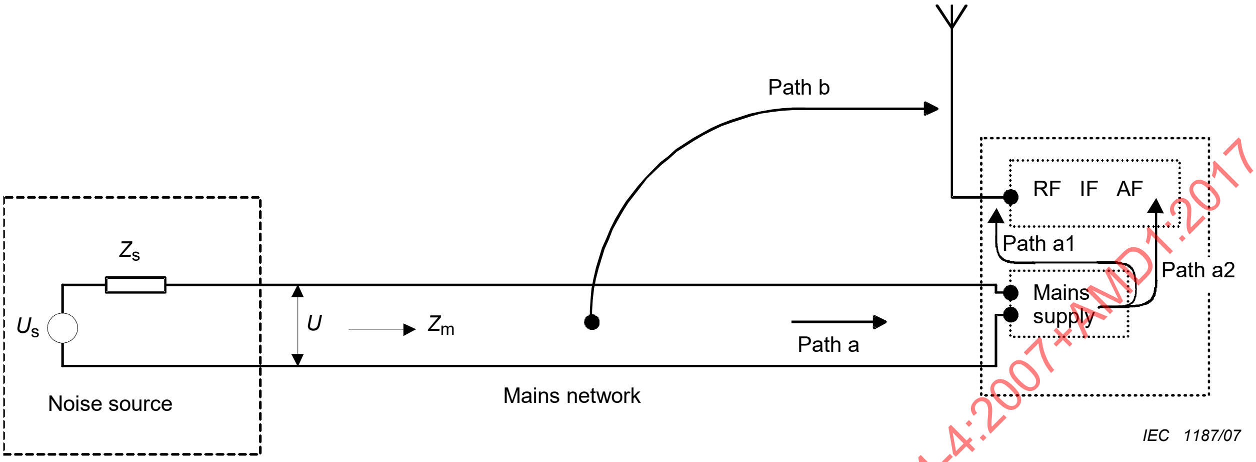


Figure 3 – Model for close coupling situations

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:

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

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

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:

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

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

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)

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

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

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

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

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

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

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:

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

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

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

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

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

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:

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

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

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

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_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

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

with

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

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

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

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

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

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

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

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

$$E_{ir} = 7/d \cdot \sqrt{P_i} \tag{33}$$

That means that

$$\mu_{ir}/\text{dB}(\mu\text{V/m}) = 20\,\lg(7/d)/\text{dB}(\Omega^{1/2}/\text{m}) + \mu_u/\text{dB}(\mu\text{V}) - 0{,}5\mu_z/\text{dB}(\Omega^{1/2}) - \mu_a/\text{dB}$$

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

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

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:

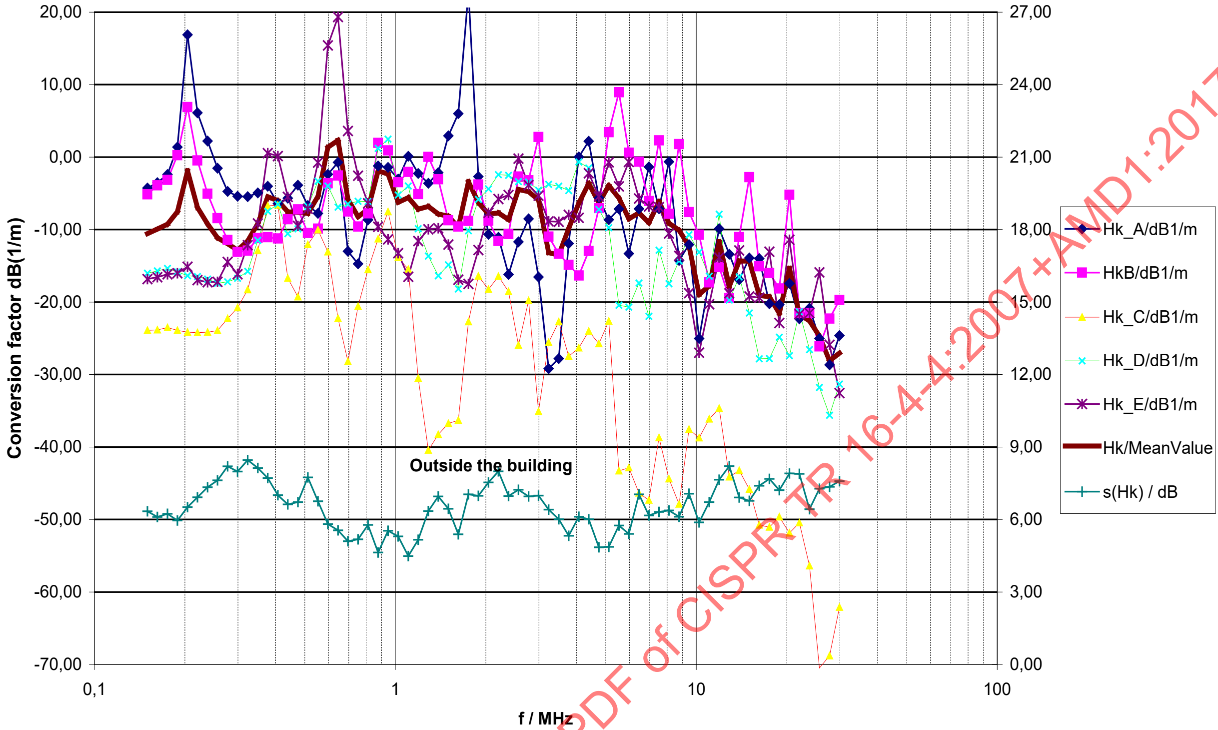
In the long and medium wave frequency bands, the disturbance field strength should be measured with a loop antenna, whereas in the short wave frequency bands, the disturbance field strength should be measured with a highly balanced shortened dipole antenna (it is not possible to use rod antennas in buildings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



IEC 1188/07

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).

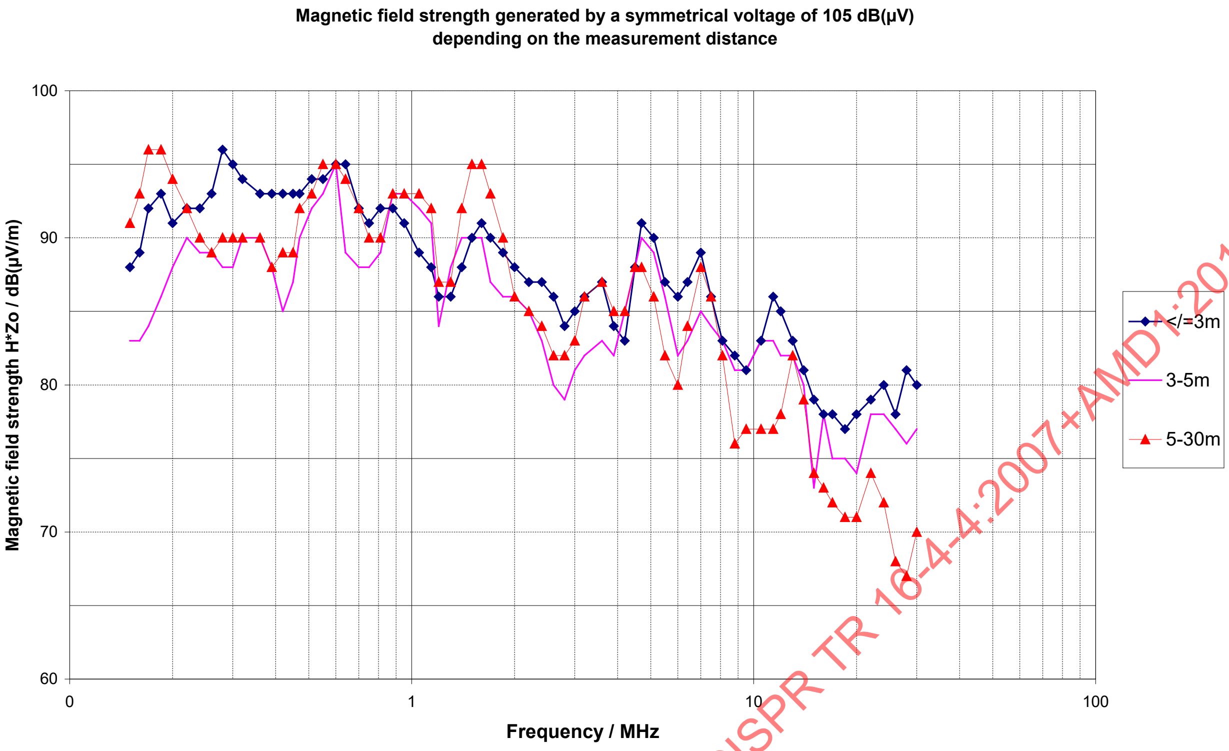


Figure 5 – Example of conversion factors – field strength generated by differential-mode voltage – at feed point, found in practice

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.)

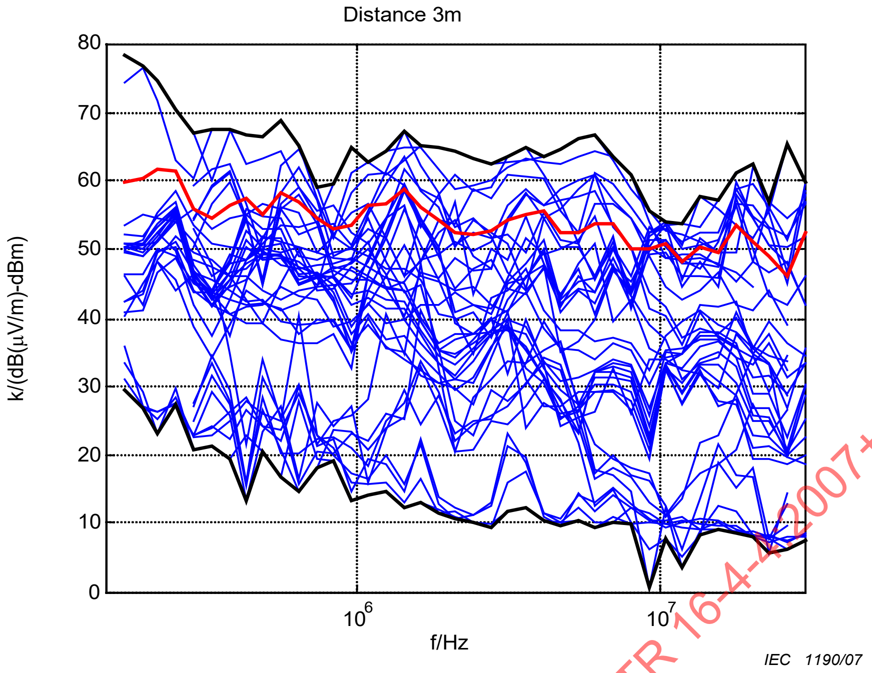


Figure 6 – Example of conversion factors – field strength generated by differential-mode voltage – outside buildings and electrical substations, found in practice

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.

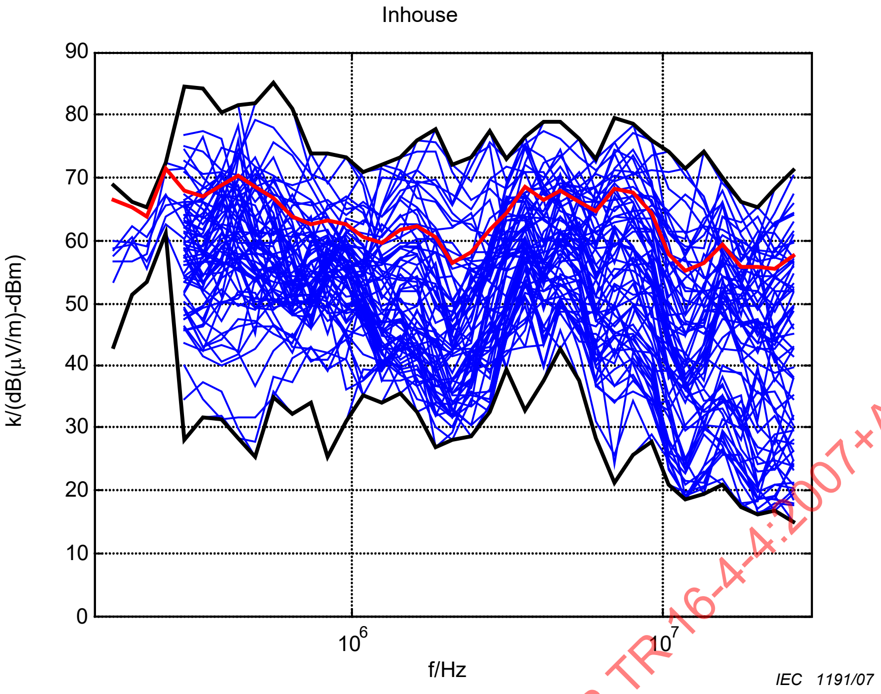


Figure 7 – Example of conversion factors – field strength generated by differential-mode voltage – inside buildings, found in practice

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:

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

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(µV/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(µV/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(µV/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(µV/m)	Corresponding limit at 30 m from boundary dB(µV/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(µv/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(μV/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(μV/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(μV/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(μV/m)	Corresponding limit at 30 m from boundary dB(μV/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(μV/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(μV/m)	Protection ratio dB	Permissible interference field at receiving antenna dB(μV/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(μv/m)	Building attenuation dB	Allowance for probability dB	Corresponding practical limit at 30 m from boundary dB(μV/m)	Corresponding limit at 30 m from boundary dB(μV/m)	Proposal for revision of CISPR limits at 30 m on a test site dB(μv/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

$$E_{\mathrm{Limit}} = \mu_i + t_\beta \sigma_i \qquad (36)$$

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

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

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

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

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

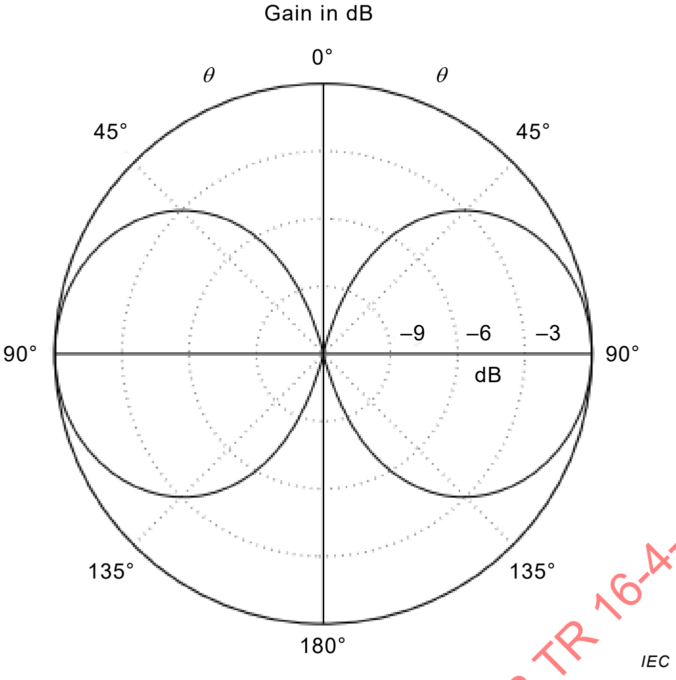


Figure 8 – horizontal plane radiation pattern on a small purely magnetic antenna

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.

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

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

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}

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

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.

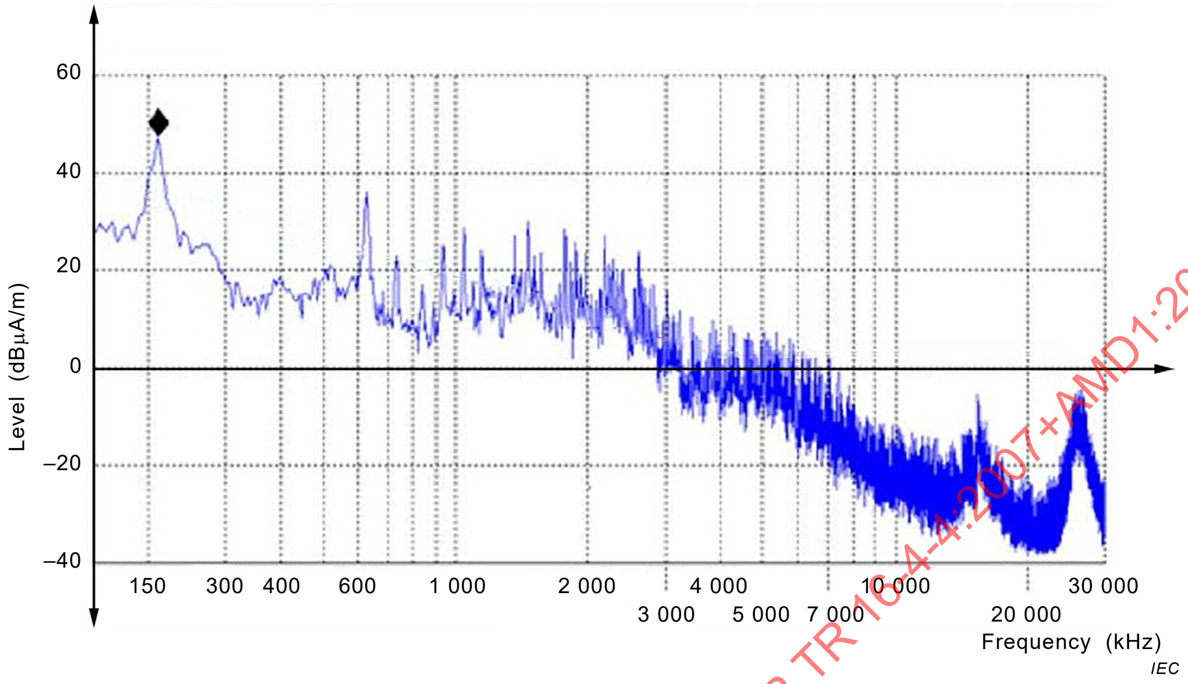


Figure 9 – typical source of magnetic field disturbance

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}

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

5.6.6 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.