TECHNICAL REPORT

CISPR 16-4-4

First edition
2003-11

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

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FOREWORD

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CISPR 16-4-4, which is a technical report, has been prepared by CISPR subcommittee A: Radio interference measurements and statistical methods.

This first edition of CISPR 16-4-4, together with CISPR 16-4-1, CISPR 16-4-3 and the second edition of CISPR 16-3, cancels and replaces the first edition of CISPR 16-3, published in 2000, and its amendment 1 (2002). It contains the relevant clauses of CISPR 16-3 without technical changes.

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

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

The committee has decided that the contents of this publication will remain unchanged until 2004. At this date, the publication will be

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- withdrawn;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

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

Recommendation 2/2 – p/o CISPR 7B, 1975; CIS/A(CO)67 , 1992; CIS/A(CO)67A, 1993; Report 61 – CISPR 23:1987; CISPR/A(Sec)81, 1987.

INTRODUCTION

CISPR 16-1, CISPR 16-2, CISPR 16-3 and CISPR 16-4 have been reorganised into 14 parts, to accommodate growth and easier maintenance. The new parts have also been renumbered. See the list given below.

Old CISPR 16 publications

CISPR 16-1	Radio disturbance and immunity measuring apparatus
CISPR 16-2	Methods of measurement of disturbances and immunity
CISPR 16-3	Reports and recommendations of CISPR
CISPR 16-4	Uncertainty in EMC measurements

New CISPR 16 publications

CISPR 16-1-1	Measuring apparatus
CISPR 16-1-2	Ancillary equipment – Conducted disturbances
CISPR 16-1-3	Ancillary equipment – Disturbance power
CISPR 16-1-4	Ancillary equipment – Radiated disturbances
CISPR 16-1-5	Antenna calibration test sites for 30 MHz to 1 000 MHz
CISPR 16-2-1	Conducted disturbance measurements
CISPR 16-2-2	Measurement of disturbance power
CISPR 16-2-3	Radiated disturbance measurements
CISPR 16-2-4	Immunity measurements
CISPR 16-3	CISPR technical reports
CISPR 16-4-1	Uncertainties in standardised EMC tests
CISPR 16-4-2	Measurement instrumentation uncertainty
CISPR 16-4-3	Statistical considerations in the determination of EMC compliance of mass-produced products
CISPR 16-4-4	Statistics of complaints and a model for the calculation of limits

More specific information on the relation between the 'old' CISPR 16-3 and the present 'new' CISPR 16-4-4 is given in the table after this introduction (TABLE RECAPITULATING CROSS REFERENCES).

Measurement instrumentation specifications are given in five new parts of CISPR 16-1, while the methods of measurement are covered now in four new parts of CISPR 16-2. Various reports with further information and background on CISPR and radio disturbances in general are given in CISPR 16-3. CISPR 16-4 contains information related to uncertainties, statistics and limit modelling.

CISPR 16-4 consists of the following parts, under the general title *Specification for radio disturbance and immunity measuring apparatus and methods - Uncertainties, statistics and limit modelling:*

- Part 4-1: Uncertainties in standardised EMC tests,
- Part 4-2: Uncertainty in EMC measurements,
- Part 4-3: Statistical considerations in the determination of EMC compliance of mass-produced products,
- Part 4-4: Statistics of complaints and a model for the calculation of limits.

For practical reasons, standardised EMC tests are drastic simplifications of all possible EMI scenarios that a product may encounter in practice. Consequently, in an EMC standard the measurand, the limit, measurement instruments, set-up, measurement procedure and measurement conditions shall be simplified but still meaningful. Meaningful means that there is a statistical correlation between compliance of the product with a standardized EMC test and a high probability of actual EMC of the same product during its life cycle. Part 4-4 provides statistically based methods to derive meaningful disturbance limits for the protection of radio services.

In general, a standardized EMC test must be developed such that reproducible results are obtained if different parties perform the same test with the same product. However, various uncertainty sources and influence quantities cause that the reproducibility of a standardized EMC test is limited. Part 4-1 consists of a collection of informative reports that deal with all relevant uncertainty sources that may be encountered during EMC compliance tests. Typical examples of uncertainty sources are the product itself, the measurement instrumentation, the set-up of the product, the test procedures and the environmental conditions.

Part 4-2, deals with a limited and specific category of uncertainties, i.e. the measurement instrumentation uncertainties. In Part 4-2, examples of measurement instrumentation uncertainty budgets are given for most of the CISPR test methods. In this part, also normative requirements are given on how to incorporate the measurement instrumentation uncertainty in the compliance criterion.

If a compliance test is performed using different samples of the same product, then the spread of the EMC performance of the product samples shall be incorporated also in the compliance criterion. Part 4-3 deals with the statistical treatment of test results in case compliance test are performed using samples of mass-produced products. This treatment is well known as the 80%-80% rule.

Part 4-4 contains forms for statistics of complaints to be applied by National Authorities and describes methods to determine limits. For this purpose the basis for the protection of radio services, the probability of interferences, the measurement procedures and the characteristic of radio services are described. On the basis of the models for the generation of disturbance for the radiation coupling and for mains coupling respectively the limits of disturbance field strength and disturbance voltage are calculated for the measurement on the test site.

TABLE RECAPITULATING CROSS-REFERENCES

First edition of CISPR 16-3 Clauses, subclauses	First edition of CISPR 16-4-4 Clauses
1.1	1
1.2	2
1.3	3
2.1	4
3	5
Annex 3.6-A	Annex 5.6-A
Figures	Figures
15, 16	1, 2

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

1 Scope

This part of CISPR 16-4 describes the calculation of limits for disturbance field strength and disturbance voltage for the measurement on the test site on the basis of models for the generation of disturbance for radiation coupling respectively for mains coupling.

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.

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

CISPR 16-1 (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods – Radio disturbance and immunity measuring apparatus*

CISPR 16-2, (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods – Methods of measurement of disturbances and immunity*

CISPR 16-3, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 3: CISPR technical reports*

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*

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 Definitions

None of the definitions of CISPR 16-3:2000 apply to this part of CISPR 16. For further definitons see IEC 60050(161).

4 Recommendation 2/3: Statistics of complaints and sources of interference

(This recommendation replaces Recommendation 2/2 in CISPR 7B).

The CISPR,

CONSIDERING

a) that many administrations regularly publish statistics on interference complaints;

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

c) that, at present, varied and ambiguous presentation often renders this comparison difficult,

RECOMMENDS

1 that the statistics supplied by National Committees should be in such a form that the following information may be readily extracted:

1.1 number of complaints as a percentage of the total number of receiving licences for television, sound broadcasting and other services;

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 subclauses 1.1, 1.2 and 1.3;

2 that the terms used in publication of statistics as recommended in clause 3 should have the following meaning:

2.1 *complaint:* a request for assistance made to the interference service by a listener or a viewer who complains that his reception is degraded by interference. For the purpose of these statistics, one complaint will be recorded for each frequency band for which a confirmed complaint has been received;

2.2 *source:* a source of interference is the apparatus or installation which causes interference. 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 in the statistics is determined by the interference 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, both active generators of electrical energy and apparatus and installations which cause interference by secondary effects (secondary modulation) are included. See also Appendix II for a complete list;

2.3 *cause of complaint other than a source:* a reason for unsatisfactory reception in a case in which no source is concerned. See also Appendix II for a complete list;

3 that statistics should cover a complete calendar year; they should whenever possible be presented in the following form, without necessarily employing the finer categories listed in Appendix II. It s not intended to exclude further subdivisions; these are desirable, but they should fit into the scheme of the standard form;

the code numbers refer to the items listed in Appendices I and II;

Statistics of interference complaints

Source of interference or other cause of complaint						Number of complaints per service from each source					
Classification code				Description	Total number in each classification	Broadcasting [a]					Other services [b]
						Sound [c]		Television [c]			
						LF/ MF/ HF	II	I	III	IV/V	
A	1	1									
	2	1									
		etc. as in the appendices									
					Totals						

[a] LF = low frequency (long waves);

MF = medium frequency (medium waves);

HF = high frequency (short waves).

These three bands may either be grouped together, as shown, or dealt with separately.

II = Band II (VHF/FM)

I = Band I (VHF/television)

III = Band III (VHF/television);

IV/V = Band IV/V (UHF/television).

[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.

Appendix I to Recommendation 2/3: Classification of sources of interference and other causes of complaint

Main categories

Classification code	Description of the source
A	Industrial scientific and medical RF apparatus
A.1	Industrial and scientific RF apparatus
A.1.1	Apparatus tuned to free radiation frequency
A.1.2	Apparatus not tuned to free radiation frequencies
A.2	Medical radio-frequency apparatus
A.2.1	Apparatus tuned to free radiation frequencies
A.2.2	Apparatus not tuned to free radiation frequencies
A.3	Sparking apparatus (except ignition)
B	Electric power supply, distribution and traction
B.1	AC voltages exceeding 100 kV
B.1.1	Power lines overhead
B.1.2	Generating and switching stations
B.2	DC voltages exceeding 100 kV
B.2.1	Power lines overhead
B.2.2	Converting stations

Classification code	Description of the source
B.3	Voltages 100 kV to 1 kV (subdivision as for B.1)*
B.4	Voltages 1 kV to 450 kV (subdivision as for B.1)*
B.5	Low tension power supply and distribution (<450 V)
B.5.1	Power lines overhead
B.5.2	Generating and switching stations
B.6	Electric traction
B.6.1	Railways
B.6.2	Tramways
B.6.3	Trolley buses
C	Electricity consumers' equipment (industrial and similar)
C.1	Generators
C.2	Motors (P > 700 W)
C.2.1	Rated power P: 700 W < P ≤ 1 000 W
C.2.2	Rated power P: 1 000 W < P ≤ 2 000 W
C.2.3	Rated power P: 2 000 W < P
C.3	Contacts
C.4	Ignition
C.5	Rectifiers
C.6	Convertors
C.7	Diode thyristor and thyratron control equipment
C.8	Cattle fences
D	Low-power appliances as normally used in households, offices and small workshops
D.1	Motors (up to and including 700 W)
D.2	Contact devices
D.3	Diode, thyristor and thyratron control equipment (less than 1 000 W)
E	Gaseous discharge and other lamps
E.1	Fluorescent lamps
E.2	Neon signs
E.3	Filament lamps
F	Receiving installations
F.1	Sound broadcast receivers
F.2	Television receivers
F.3	Amplifiers and common aerial reception systems for broadcasting
F.4	Non-broadcasting receivers
G	Ignition systems of internal combustion engines
H	Identified sources other than those specified

* For convenience of analysis, the same subdivision is used for all voltage ranges. In those cases where a classification does not apply, for example, corona for low voltages, the category should remain blank

Classification code	Description of the source
I	Other causes of complaint
I.1	Telecommunication
I.1.1	Radio communication transmitters
I.1.1.1	Fundamental radiation
I.1.1.2	Harmonic radiation
I.1.1.3	Spurious radiation
I.1.2	Telecommunication by wire
I.2	Faults of the receiving installations
I.3	Receiver characteristics
I.4	Weak or faulty signals
I.5	Atmospheric disturbances
I.6	Unidentified sources of interference
I.7	Interference not observed
J	Information technology equipment
J.1	Data processing equipment (DPE)
J.1.1	Large DPE in computer rooms
J.1.2	Smaller plugable DPE not in dedicated rooms
J.1.3	Home computers and home video games
J.2	Local area network
J.3	Commercial video games
J.4	Telephone exchanges and other digital telecommunication equipment

Appendix II to Recommendation 2/3: Classification of sources of interference and other causes of complaint

Detailed categories

Classification code	Description of the source
A	Industrial scientific and medical RF apparatus
A.1	Industrial and scientific RF apparatus
A.1.1	Apparatus tuned to free radiation frequency
A.1.1.1	Drying non-metals
A.1.1.2	Plastic pre-heaters
A.1.1.3	Plastic seam welders
A.1.1.4	Wood glue drying
A.1.1.5	Microwave heating
A.1.1.6	Microwave cooking
A.1.1.7	Ultrasonic soldering and cleaning
A.1.1.8	Food treatment heaters (for example, fish thawing)
	…
A.1.1.20	Other
A.1.2	Not tuned to free radiation frequencies
A.1.2.1 to A.1.2.20	As for A.1.1.1 to A.1.1.20
A.2	Medical radiofrequency apparatus
A.2.1	Apparatus tuned to free radiation frequencies
A.2.1.1	Diathermy
A.2.1.2	Ultrasonic medical
A.2.1.3	Cauterization
	…
A.2.1.20	Other
A.2.2	Apparatus not tuned to free radiation frequencies
A.2.2.1 to A.2.2.20	As for A.2.1.1 to A.2.1.20
A.3	Sparking apparatus (except ignition)
A.3.1	RF excited arc welder
A.3.2	Surface erosion of plastics
A.3.3	Surface erosion of metals
A.3.4	Spectrograph
A.3.5	Spark diathermy
	…
A.3.20	Other
B	Electric power supply, distribution and traction
B.1	AC voltages exceeding 100 kV
B.1.1	Power lines overhead
B.1.1.1	Corona effect
B.1.1.2	Insulators
B.1.1.3	Presence of foreign objects on line
	…
B.1.1.20	Other

Classification code	Description of the source
B.1.2	Generating and switching stations
B.1.2.1	Generating stations
B.1.2.2	Switching stations
B.1.2.3	Transformer stations
B.1.2.4	Saturated transformers
	…
B.1.2.20	Other
B.2	DC voltages exceeding 100 kV
B.2.1	As for B.1.1
B.2.2	Converting stations
B.3	Voltages 100 kV to 1 kV (subdivision as for B.1)*
B.4	Voltages 1 kV to 450 V (subdivision as for B.1)*
B.5	Low tension power supply and distribution (<450 V)
B.5.1	Power lines overhead
B.5.1.1	Presence of foreign objects on line
B.5.1.2	Equipment faults
	…
B.5.1.20	Other
B.5.2	Generating and switching stations
B.5.2.1 to B.5.2.20	
B.6	Electric traction
B.6.1	Railways
B.6.1.1	Overhead distribution, high voltage
B.6.1.2	Overhead distribution, medium voltage
B.6.1.3	Rail distribution
B.6.1.4	Locomotive
	…
B.6.1.20	Other
B.6.2	Tramways
B.6.3	Trolley buses
C	Electricity consumers' equipment (industrial and similar)
C.1	Generators
C.2	Motors (P > 700 W)
C.2.1	Rated power P: 700 W < $P \leq$ 1 000 W
C.2.1.1	Lifts
C.2.1.2	Central heating
	…
C.2.1.20	Other
C.2.2	Rated power P: 1 000 W < $P \leq$ 2 000 W
C.2.2.1	Lifts
C.2.2.2	Central heating
	…
C.2.2.20	Other
* Appendix A of CISPR Recommendation 22/3 gives a list of such appliances	

Classification code	Description of the source
C.2.3	Rated power P: 2 000 W < P
C.2.3.1	Lifts
C.2.3.2	Central heating
	…
C.2.3.20	Other
C.3	Contacts
C.3.1	Lifts
C.3.2	Central heating
	…
C.3.20	Other
C.4	Ignition
C.4.1	Central heating
	…
C.4.20	Other
C.5	Rectifiers
C.6	Convertors
C.7	Diode thyristor and thyratron control equipment
C.8	Cattle fences
	…
C.20	Other installations
D	Low power appliances as normally used in households, shops, offices and small workshops
D.1	Motors (up to and including 700 W)*
D.1.1	Tools
D.1.1.1	Portable
D.1.1.2	Fixed
D.1.2	Household appliances
D.1.3	Shop and office appliances
	…
D.1.20	Other
D.2	Contact devices**
D.2.1	Thermostats
D.2.2	Other contact devices
D.3	Diode, thyristor and thyratron control equipment (less than 1 000 W)
E	Gaseous discharge and other lamps
E.1	Fluorescent lamps
E.2	Neon signs
E.3	Filament lamps
E.3.1	Vacuum
E.3.2	Gas filled
	…
E.20	Other

* Appendix A of CISPR Recommendation 22/3 gives a list of such appliances.

** See Appendix III of CISPR Recommendation 50.

Classification code	Description of the source
F	Receiving installations
F.1	Sound broadcast receivers
F.1.1	AM receiver
F.1.2	FM receiver
F.2	Television receivers
F.2.1	Local oscillator
F.2.1.1	Fundamental
F.2.1.2	Harmonic
F.2.2	Intermediate frequency radiation
F.2.3	Time base oscillator
F.2.4	Time base parasitic oscillation is, for example, Barkhausen oscillations
	…
F.2.20	Other
F.3	Amplifiers and common aerial reception systems for broadcasting
F.4	Non-broadcasting receivers
G	Ignition systems of internal combustion engines
G.1	Motor vehicles
G.2	Boats
G.3	Powered appliances (for example, lawn mowers)
	…
G.20	Other engines
H	Identified sources other than those specified
I	Other causes of complaint
I.1	Telecommunication
I.1.1	Radio communication transmitters
I.1.1.1	Fundamental radiation
I.1.1.1.1	Broadcasting stations
I.1.1.1.2	Amateur stations
I.1.1.1.3	Land mobile stations
	…
I.1.1.1.20	Other
I.1.1.2	Harmonic radiation
I.1.1.2.1	Broadcasting stations
I.1.1.2.2	Amateur stations
I.1.1.2.3	Land mobile stations
I.1.1.3	Spurious radiation
I.1.1.3.1 to I.1.1.3.20	As for I.1.1.1
I.1.2	Telecommunication by wire
I.2	Faults of the receiving installation
I.2.1	Inefficient aerial installation
I.2.2	Faulty receivers
I.2.3	Maladjustment of receiver
I.2.4	Low mains voltage

Classification code	Description of the source
I.3	Receiver characteristics
I.3.1	Second (image) channel response
I.3.2	Other spurious responses
I.3.3	Intermodulation
I.3.4	Inadequate receiver immunity
I.4	Weak or faulty signals
I.4.1	Outside service area
I.4.2	Shadow area
I.4.3	Multipath reception
I.4.3.1	Power lines
I.4.3.2	Other
I.5	Atmospheric disturbances
I.6	Unidentified sources of interference
I.7	Interference not observed
J	Information technology equipment
J.1	Data processing equipment
J.1.1	Large DPE in computer rooms
J.1.2	Smaller plugable DPE not in dedicated rooms
J.1.3	Home computers and home video games
J.2	Local area network
J.3	Commercial video games
J.4	Telephone exchanges and other digital telecommunication equipment

5 A model for the calculation of limits

5.1 Introduction

A harmonized method of calculation is an important pre-condition for the efficient discussion of CISPR limits by National Committees and the adoption of CISPR Recommendations.

5.1.1 Generation of EM disturbances

CISPR Recommendations 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 have 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 electronic 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. 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 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 at the input of a receiver being greater than the minimum permissible signal-to-interference ratio. That is:

$$P\left[R(\mu_\mathrm{R};\sigma_\mathrm{R}) \geq R_\mathrm{P}\right] = a$$

where

$P[\ ]$	is the probability function;
$R(\mu_\mathrm{R};\sigma_\mathrm{R})$	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;
a	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 ITU-R Report 829.

5.2.1 Derivation of probability of interference

The Radio Regulations, No. 160, 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

$$P(\mathrm{I}) = P(\mathrm{A\ and\ B\ and\ C\ and\ D^*}) \tag{5.1}$$

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

$$P(\mathrm{I}) = [P(\mathrm{B}|\mathrm{A}) - P(\mathrm{D}|\mathrm{A\ and\ C})]\ P(\mathrm{A\ and\ C}) \tag{5.2}$$

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

$$P'(\mathrm{I}) = P(\mathrm{B\ and\ C\ and\ D^*}|\mathrm{A}) \tag{5.3}$$

which can be reduced to:

$$P'(\mathrm{I}) = [P(\mathrm{B}|\mathrm{A}) - P(\mathrm{D}|\mathrm{A\ and\ C})]\ P(\mathrm{C}|\mathrm{A}) \tag{5.4}$$

5.2.1.2 Discussion of equations (5.2) and (5.4)

First, consider the difference between equation (5.2) and (5.4). The probability of interference can be interpreted as the fraction of time that interference exists. In equation (5.2), this fraction is the number of seconds of interference during a time period divided by the number of seconds of interference 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 computer when the system is designed. It can 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) and statistical data on radio noise (for example, Reports 322 and 670).

Note Recommendation 370 is available as ITU-R Rec. P.370-7, and Report 322 is essentially in ITU-R Rec. P.372-7. Other Reports (e.g. Rep. 670 and 656) are in former CCIR Publications.

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.

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 (5.2).

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 (5.2) and (5.4) 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 RFI limits. 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.

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, 3-30 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 30-300 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: 10 kHz to 18 GHz.

For the statements given above, it follows that some similarity exists between closed 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 the practical situations, however, the good correspondence between close/remote coupling and near/far-field conditions is useful in the 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. Inside the receiver the noise signal is coupled from the mains terminals to sensitive circuits of the receiver.

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 completely undefined.
– Under far-field conditions the attenuation formula is

$$y = kd^{x} \tag{5.5}$$

where

y = attenuation factor;

d = distance;

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 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 the specification of an RFI 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 RFI meter (CISPR receiver) as specified for the relevant frequency range.

5.3.2.1 Interference voltage at the mains terminals

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 terminals is used as a measure for the interfering potential of a source in this frequency range.

This RFI voltage at the mains terminals 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. The artificial mains network generally recommended by CISPR is a 50 Ω/50 μHV-network which introduces a parallel impedance of 50 Ω/50 μH V-network between each mains terminal and reference ground.

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

5.3.2.2 Interference voltage at the signal terminals

Imperfections of the symmetry in circuits carrying wanted symmetrical signals will produce unwanted asymmetric signals at the terminals. In asymmetric (coaxial) terminals unwanted external currents can be conducted in 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 a delta network instead of a V-network is preferred.

5.3.2.3 RFI 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 interference power that can be radiated from the external lead of the appliance.

The main part of an absorbing clamp is a ferrite cylinder clamped around the disturbance carrying lead which attenuates conducted asymmetric currents by absorption. At the input end of the cylinder a current probe is fixed.

The ferrite cylinder operates as an isolator for RFI signals between mains and noise source and offers a specified, resistive impedance to the lead at the position of the current probe. So the output voltage of the current probe is a measure for the RFI power entering the absorbing clamp.

The device is clamped around the lead under test and moved along the lead to a position of maximum output reading. This operation actually adjusts the determination between source impedance and clamp input impedance (maximizing the RFI output power) through the variable lead section between source and clamp.

Under this condition the RFI 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 RFI 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 was originally recommended for the measurement of small appliances in the frequency range 30 MHz to 300 MHz. There is, however, a tendency to use the absorbing clamp in the frequency range up to 1 000 MHz.

The use of the clamp is restricted at the lower part of the frequency region because of the poor absorbing characteristics of the ferrite material. It is therefore recommended for frequencies above 30 MHz.

5.3.2.4 Field-strength measurement

The unwanted field strength produced by RFI signals is likely to be the most straightforward criterion for the interference potential of an RFI 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 RFI 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 (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 test site. Such a test site introduces inaccuracies by the variable reflections from the operator and from the ground (influence of moisture and season) and by the interference of ambient transmitter fields. It also reduces the work time due to poor weather and other climatic conditions. These drawbacks can be partly eliminated by the use of anechoic rooms in the frequency range above 30 MHz.

Another drawback of field-strength measurements is the complex radiation diagram and its dependence on the test set-up which 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 RFI power measurements with a reverberating chamber

The reverberating chamber method is essentially a radiation substitution method inside a screened cage and is used in the microwave frequency range. By using rotating reflection plates, 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, the radiation of a device and the conduction and radiation of connected cables, particularly the main 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 1 – Guidance survey of RFI measuring methods

Frequency MHz	**Terminal voltage**	**Asymm. current**	**Absorbing clamp**	**Field strength**	**Subst. radiation**	**Reverb. chamber**
0,01 – 0,15	+	+	–	0	–	–
0,15 – 30	+	+	–	0	–	–
30 – 300	–	0	+	+	0	–
300 – 1 000	–	0	0	+	+	–
Above 1 000	–	–	–	+	+	+

Where
+ = to be recommended;
0 = usable;
– = not normally usable.

5.3.3 RFI signal waveforms and associated spectra

An important aspect is the RFI 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 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 (ISM equipment) or of low power (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 10 kHz to 18 GHz.

– Narrowband RFI from a broadband spectrum – 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.
– 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), for example, pulse derived from the mains frequency (commutator motors, thyristor voltage regulators).

  The frequency curve 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 is considered by CISPR over the frequency range 150 kHz to 300 MHz.

– Discontinuous broadband RFI – Switching operations by means of a hard contact (spark) generates short bursts of noise. Short-duration bursts of RFI 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 interference 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 the interfered radio services with respect to RFI are very important as well. The main radio services in residential areas which suffer from RFI are broadcasting and (land) mobile 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.

In residential areas with private receiving antennas the RFI radiation from noise sources and from mains cables is of major importance. Broadcast signals distributed through a cable system are less vulnerable because of the more suitable location which can be selected for the common receiving antenna, but if RFI is coupled to such an antenna the interference is distributed to all subscribers.

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 RFI waveform. Narrowband and broadband sources produce different types of annoyance. Subjective tests have shown that for equivalent subjective assessment, narrowband RFI should be of significantly lower amplitude than broadband RFI (quasi-peak measured) in the 0,15 MHz to 30 MHz range.

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 (mainly narrowband FM), traffic noise sources (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.

Broadcasting and mobile services may be interfered by narrowband sources as well (ISM equipment, data processing equipment, receiver oscillators, etc.). The radiated RF power from 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.

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 services, however, a much higher degree of confidence is necessary. The actual annoyance in an interfered radio service not only depends on the RFI field strength, but on the wanted signal level as well. The radio of wanted-to-unwanted input level which procures a specified quality of performance is called RF protection ratio. The wanted signal level depends on the natural noise level which may be much higher than the receiver noise level, particularly in the lower part of the 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 all types of sources should be suppressed as much as possible to an equal level of noise output.

In some cases, however, this may be in contradiction with other requirements for suppression measures such as feasibility from physical conditions or from electric safety reasons and not in the least from an economic point of view.

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 1) was developed to derive radiation limits for the case of in-band interference (in the tuned channel). For the relevant radio services in the allocated frequency bands the protection ratio is determined. This protection ratio in ITU documents is given for disturbing radio service with the same modulation. The protection ratio for any disturbance radiation may be different.

From this protection ratio and from the minimum or nominal wanted field strength (field strength to be protected), the acceptable disturbance field strength at the receiving antenna input is calculated; that means that different types of modulation of the disturbance field strength has to consider a distinct from the protection ratios given in ITU documents. A minimum operational distance between noise source and receiving antenna is specified and with the use of an estimated or empirical propagation factor, the acceptable disturbance field strength at a specified measuring distance is calculated. Next some additional factors should be introduced for the screening factor of buildings and for the probability of actual interference under operational conditions. Such a probability factor 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.

The final result of this procedure is a calculated limit which is a good basis for an operational limit guaranteeing that the requirements of the protection ratio is 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 not (yet) available and that in those cases rough estimations are used.

Moreover the interfering effect of out-of-band signals 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 2. 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 an RF-impedance Z_m to the source and transfers the energy from the noise source to the mains input 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 the coupling between supply circuit and antenna/RF circuits inside the receiver;
b) the path of disturbance conducted along and radiated by the mains network and coupled directly to the receiving antenna outside or inside the receiver.

In the case of external antennas, the RF power coupled through the external path b exceeds the power via path appreciably. Moreover the internal coupling is determined by the mains immunity characteristics 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. Therefore the attention is mainly focused on path b. For internal (ferrite) antennas no clear distinction can be made between paths a and b.

The approach of the modelling starts in the same way as in the case of remote coupling. The acceptable disturbance field strength at the receiving antenna is calculated from protection ratio and field strength to be protected in the relevant frequency bands. The following step is the coupling factor 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 limits derived from mains decoupling factors.

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 is defined for a fixed simulated impedance (artificial mains network impedance), in order to get reproducible measuring results during tests. If a noise source is coupled to an actual mains network the load impedance of that 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.

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 Basic model

This section contains the basic mathematical model used. 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 lognormal distribution.

5.4.1 Generation of EM disturbances

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

$$z = x/y \geq 1 \tag{5.6}$$

is satisfied with some probability α.

If in (5.6) x and y are random values with log-normal distribution X (dB) and Y (dB) and with parameters μ_x (dB), μ_y (dB), σ_x (dB) and σ_y (dB) will have a normal distribution with the parameters

$\mu = \mu_x - \mu_y$

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

In this case

$$\alpha = F(\mu/\sigma)_{z=0} \tag{5.7}$$

Solving (5.7) relative to μ_x or μ_y

$$\mu_x = \mu_y + t_\alpha \sigma \tag{5.8}$$

$$\mu_y = \mu_x - t_\alpha \sigma \tag{5.9}$$

where t_α is a quantile of normal distribution, corresponding to the probability level α.

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 equality is true:

$$L_x = \mu_x + t_\beta \sigma_x \tag{5.10}$$

$$L_y = \mu_y - t_\beta \sigma_y \tag{5.11}$$

where t_β is a quantile for the probability level β.

Substituting (5.8) into (5.10) and (5.9) into (5.11)

$$L_x = \mu_y + t_\alpha \sigma + t_\beta \sigma_x \tag{5.12}$$

$$L_y = \mu_x - t_\alpha \sigma + t_\beta \sigma_y \tag{5.13}$$

one is enabled by the expressions obtained for the calculation of limits for different parameters, which ascertain the radio reception quality.

5.4.2 Immunity from EM disturbances

The inequality (5.6) 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

$$\sigma = \left[\sigma_x^2 + \sigma_y^2\right]^{1/2} \quad (5.14)$$

In this case, according to (7.7), the equation for the calculation of receptor immunity limits has the following form:

$$L_x = \mu_y + t_\alpha \left[\sigma_x^2 + \sigma_y^2\right]^{1/2} - t_\beta \sigma_x \quad (5.15)$$

5.5 Application of the basic model

5.5.1 Radiation coupling

This section 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 radio antenna. The actual signal-to-interference ratio R can be expressed in terms of the wanted signal, the disturbing signal, the propagation losses and the antenna gain, as follows:

$$R = E_w\,(\mu_w{:}\sigma_w) + G_w(\mu_{Gw}{:}\sigma_{Gw}) - [E_i(\mu_i{:}\sigma_i) - G_i(\mu_{Gi}{:}\sigma_{Gi}) + L_o(\mu_{Lo}{:}\sigma_{Lo}) + L_b(\mu_{Lb}{:}\sigma_{Lb}) \quad \text{dB} \quad (5.16)$$

where

E_w is the actual value of the wanted signal as a function of its mean value (μ_w) and the standard deviation (σ_w);

E_i is the value of the disturbance signal at a preset distance 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 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 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 when it is propagated through free space without obstacles as a function of its mean value (μ_{Lo}) and standard deviation (σ_{Lo});

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}).

It is assumed that all the variables on the right-hand side of equation (5.16) obey a normal distribution law, then the distribution factors are related as follows:

$$\mu_R = \mu_w + \mu_{Gw} - \mu_i - \mu_{Gi} + \mu_{Lo} + \mu_{Lb} \quad \text{dB} \quad (5.17)$$

$$\sigma_R^2 = \sigma_w^2 + \sigma_{Gw}^2 + \sigma_i^2 + \sigma_{Gi}^2 + \sigma_{Lo}^2 + \omega_{Lb}^2 \quad (5.18)$$

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

$$\Phi\,[-(R_p - \mu_R) \,/\, \sigma_R] = a \tag{5.19}$$

therefore:

$$\mu_R = R_p + t_a \sigma_R \tag{5.20}$$

where $t_a = \Phi^{-1}\,(a)$

By combining equations (5.17), (5.18) and (5.20) an expression is obtained for the permissible mean value of the disturbance field strength at a preset distance from the source of disturbance:

$$\mu_i = \mu_w + \mu_{Gw} - \mu_{Gi} + \mu_{Lo} + \mu_{Lb} - R_p - t_a\,[\sigma_w^2 + \sigma_{Gw}^2 + \sigma_i^2 + \sigma_{Gi}^2 + \sigma_{Lo}^2 + \omega_{Lb}^2]^{1/2} \tag{5.21}$$

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

$$E = \mu_i + t_n \sigma_i \tag{5.22}$$

where

E is the limit for disturbance measured on a test site at a specified distance; and

t_n is a normalized argument of the distribution function which corresponds to a probability level of compliance with the limits.

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

$$\mu_{Lo} = 20\,\log_{10}\,[r^x/d] \tag{5.23}$$

where

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

d is the specified test distance on the measurement site;

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

Combining equations (5.21), (5.22) and (5.23) the limit is given by:

$$E = \mu_w + \mu_{Gw} - \mu_{Gi} + 20\,\log_{10}\,[r^x/d] + \mu_{Lb} - R_p - t_n \sigma_i$$

$$- t_a\,[\sigma_w^2 + \sigma_{Gw}^2 + \sigma_i^2 + \sigma_i^2 + \sigma_{Gi}^2 + \sigma_{Lo}^2 + \omega_{Lb}^2]^{1/2} \tag{5.24}$$

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_n = 0,84.

5.5.2 Mains coupling

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

$$P(R > R_p) \geq \alpha \tag{5.25}$$

where

R is the signal-to-disturbance ratio;

R_p is the minimum acceptable signal-to-disturbance ratio;

α is a specified value representing the reliability of communications.

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

$$R = V_w - V_i + K \quad \text{dB} \tag{5.26}$$

where

V_w is an effective value of wanted signal at the receiver input;

V_i is a value of a specified component of the electromagnetic disturbance (i.e., of voltage, field strength, power, etc.) measured in a specified way using specified equipment (i.e. a quasi-peak detector);

K is a decoupling factor defined as a ratio of V_i to an effective value of electromagnetic disturbance signal at the receiver input.

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

$$K = K_m + I \quad \text{dB} \tag{5.27}$$

where

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

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

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

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

$$L_{pr}(V_i) = U_{Ew} + U_k + R_p + t_p \sigma_{Ei} - t_r \left[\sigma_{Ew}^2 + \sigma_{Ei}^2 + \sigma_k^2\right]^{1/2} \tag{5.28}$$

U, σ^2 are expectations/variances of corresponding components; $t_r = \Phi^{-1}$, $t_p = \Phi^{-1}$ are arguments of a normal distribution function which is equal to t_r and p, respectively.

For series-produced articles CISPR recommends that $p = 0,8$; then $t_p = 0,84$. A value of τ is selected between 0,8 and 0,99, depending on a type of a radio network (radio broadcasting, air navigation, *et al*). When $\tau = 0,95$, then $t_r = 1,64$.

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 E_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.

5.6 An alternative method used for ISM equipment

5.6.1 Introduction

The purpose of this clause is to review studies made for the derivation of CISPR limits for the protection of telecommunications from interference from ISM equipment and to conclude from these a recommended method which will meet the objectives of CISPR and ITU. This clause deals only with radiation which occurs outside the bands designated by ITU for ISM use.

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 II together with the major services requiring protection. Appendix A provides a model for the calculation of limits.

5.6.2.1 Protection of communication services

The wanted field strength to be protected, the protection ratio required for the different types of ISM equipment, 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 2 by assigning appropriate values to each parameter, for example, field strength to be protection, protection ratio, etc., worst-case limits for protecting the various communication services from interference from ISM 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 ISM equipment. 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 an 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 services is urgently required and studies are being undertaken in several countries.

5.6.2.3 Probability factors

Probability of coincidence of adverse factors:

$P = P_1 \times P_2 \rightarrow P_{10}$

where

P_1 is the probability that the major lobe of the ISM 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 ISM 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 ISM 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 of limit value of ISM radiation with edge of service area condition is for the protected service;

P_{10} is the probability that buildings provide attenuation.

Table 2 – Tabulation of the method of determining limits for ISM equipment 0,150 MHz to 960 MHz

Frequency band	Service to be protected	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											
4,00 to 15,00	Fixed links Aeromobile											
15,00 to 20,00	Fixed links Aeromobile											
20,00 to 30,00	Fixed links Aeromobile											
30,00 to 68,00	TV BC Land mobile											
854,00 to 960,00	Land mobile											
100,00 to 156,00	FM BC ILS Aero-mobiles Land mobile											

Table 2 *(continued)*

Frequency band	**Service to be protected**	**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)
156,00 to 174,00	Land mobile											
174,00 to 216,00	TV BC Land mobile											
216,00 to 400,00	ILS											
400,00 to 470,00	Fixed links Land mobile											
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											

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 service from interference with the characteristics of the signal generated by ISM equipment (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 ISM equipment at which receiving installations of the relevant service are normally installed. Equipment at a different distance will be allowed for in the probability factor.

(9) The attenuation provided by buildings in which the ISM equipment 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. This approach has in the past had considerable merit, but is becoming increasingly difficult to sustain. Thus, it has been found useful to introduce several classes of limits for ISM equipment (see CISPR 11).

Annex 5.6-A

Summary of proposals for determination of limits

5.6-A.1 Experience approach

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-A.2 User and manufacturer responsibility for avoidance of interference

User regulations are in force in a number of countries.

User limits may take one of the several forms outlines as follows:

i) regulations may require users to meet certain limits if interference is caused;

ii) if interference is caused, regulations may require an ISM user to cease operations until the interference is abated;

iii) regulations based on the licensing of apparatus of this category.

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 ii) and the German regulations which take the form of item iii). In the USA the limits are considerably less stringent than those recommended by CISPR.

5.6-A.3 Calculation of limits on a worst-case basis

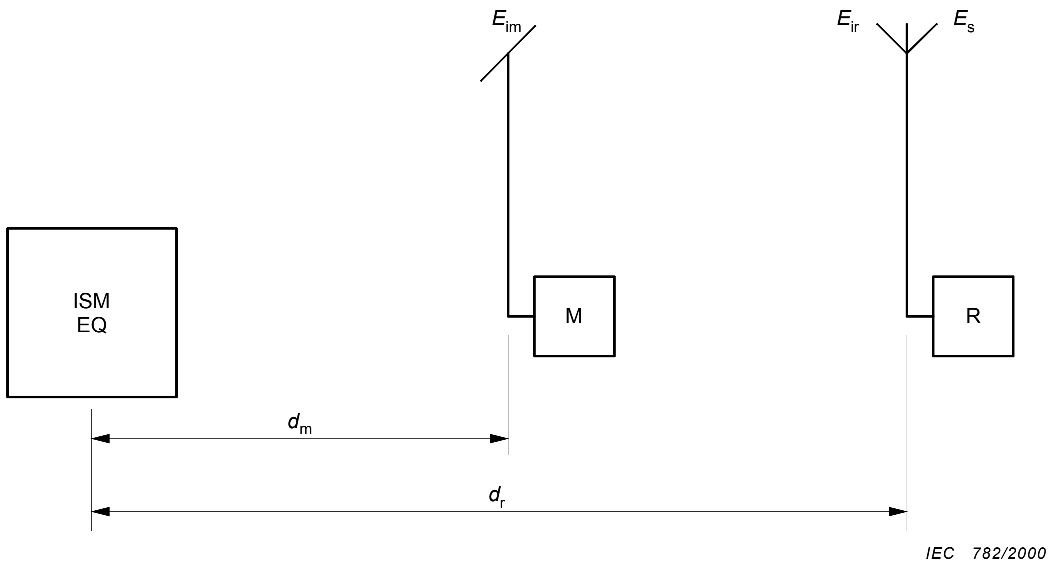
This method of arriving at limits is intended to provide a high degree of protection for all radiocommunication services. Limits are calculated using minimum values of field strength to be protected, high values of protection ratio, maximum coupling between disturbance sources and radiocommunication 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 do not contribute to the welfare and heath of the human race.

5.6-A.4 Statistical evaluation approach

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.



$$E_{ir} = E_w / S$$

E_w = wanted signal field strength to be protected

S = protection ratio

$$E_{im} = E_{ir}\ \alpha\ p\ (d_r/d_m)^x$$

E_{im} = regulated interference field strength at measuring distance d_m

α = screening factor of building

p = statistical probability factor

x = propagation coefficient

Figure 1 – Model for remote coupling situation derived disturbance field strength E_{ir} at receiving distance d_r (see 5.3.6.1)

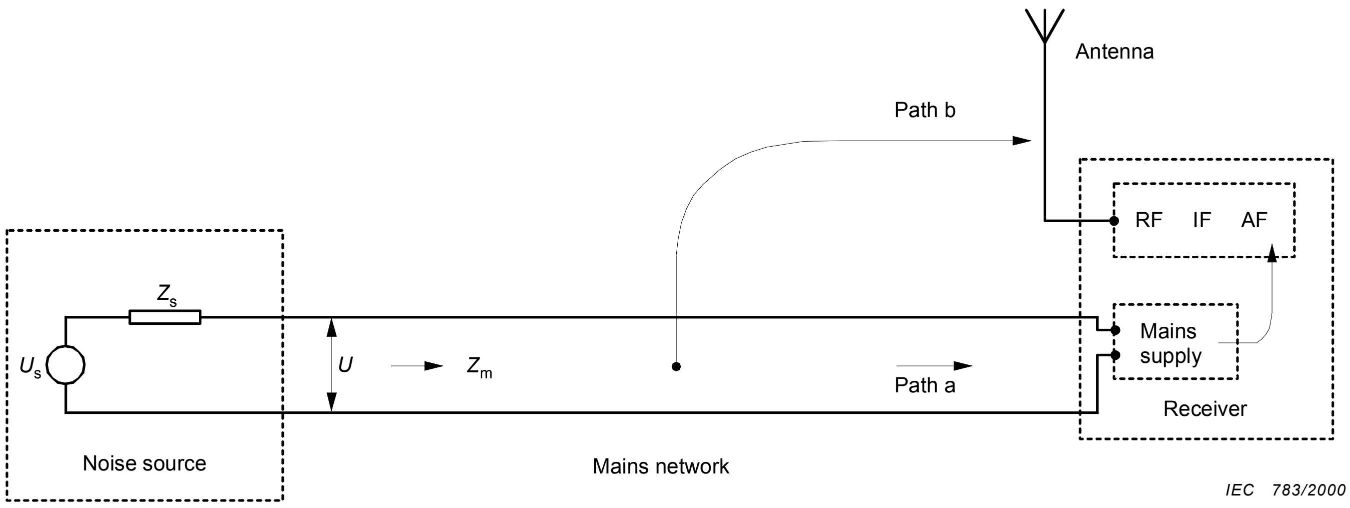


Figure 2 – Model for close coupling situations (see 5.3.6.2)

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