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# TECHNICAL REPORT

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INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

## Radio interference characteristics of overhead power lines and high-voltage equipment – Part 1: Description of phenomena

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

# RADIO INTERFERENCE CHARACTERISTICS OF OVERHEAD POWER LINES AND HIGH-VOLTAGE EQUIPMENT –

## Part 1: Description of phenomena

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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".

CISPR 18-1, which is a technical report, has been prepared by CISPR subcommittee B: Interference relating to industrial, scientific and medical radio-frequency apparatus, to other (heavy) industrial equipment, to overhead power lines, to high voltage equipment and to electric traction.

This third edition cancels and replaces the second edition published in 2010. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) updated description of the RF characteristics of spark discharges which might contain spectral radio noise components up to the GHz frequency range;

b) addition of state of the art in HVDC converter technology

The text of this technical report is based on the following documents:

| DTR | Report on voting |
|---|---|
| CIS/B/653/DTR | CIS/B/674/RVDTR |

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

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

A list of all parts of the CISPR 18 series can be found, under the general title *Radio interference characteristics of overhead power lines and high-voltage equipment,* on the IEC website.

The committee has decided that the contents of this publication 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

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# INTRODUCTION

This Technical Report is the first of a three-part series dealing with radio noise generated by electrical power transmission and distribution facilities (overhead lines and substations). It contains information in relation of the physical phenomena involved in the generation of electromagnetic noise fields. It also includes a description of the main properties of such fields and their numerical values. Its content was adjusted such as to allow for use of the lateral distance *y* for the establishment of standard profiles for the lateral radio noise field emanating from HV overhead power lines.

The technical data given in this Part 1 of the CISPR 18 series are intended to be a useful aid to overhead line designers and also to anyone concerned with checking the radio noise performance of a line to ensure satisfactory protection of wanted radio signals. The data should facilitate the use of the recommendations given in its Parts 2 and 3 dealing with

– methods of measurement and procedures for determining limits, and a

– code of practice for minimizing the generation of radio noise.

The CISPR 18 series does not deal with biological effects on living matter or any issues related to exposure to electromagnetic fields.

This document has been prepared in order to provide information on the many factors involved in protecting the reception of radio, especially (but not limited to) analogue television, and digital terrestrial television broadcasting, hereafter denominated as digital television broadcasting, from interference due to background noise generated by AC and DC high voltage overhead power lines, distribution lines, and associated equipment. The information given should be of assistance when means of avoiding or abating radio noise are being considered.

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Information is mainly given on the generation and characteristics of radio noise from AC power lines and equipment operating at 1 kV and above, in the frequency ranges 0,15 MHz to 30 MHz (a.m. sound broadcasting), 30 MHz to 300 MHz (f.m. sound broadcasting, analogue television broadcasting) and in the range 470 MHz to 950 MHz (digital television broadcasting). The special aspect of spark discharges due to bad contacts or defects is taken into account. Information is also given on interference due to DC overhead power lines for which corona and interference conditions are different from those of AC power lines. The radio broadcast services mentioned above are examples only and the information in this document relates, in a technology-neutral way, to protection of radio reception in general, for the given frequency ranges.

The general procedure for establishing the limits of the radio noise from overhead power lines and associated equipment is given, together with typical values as examples, and methods of measurement.

The clause on limits for conductor corona, which may occur in normal operation of power lines, concentrates on the low frequency and medium frequency bands as it is only in these bands where ample evidence, based on established practice, is available. Examples of limits to protect radio reception in the frequency band 30 MHz to 300 MHz are not given, as measuring methods and certain other aspects of the problems in this band have not yet been fully resolved. Site measurements and service experience have shown that levels of noise from power lines generated by conductor corona at frequencies higher than 300 MHz are so low that interference is unlikely to be caused to analogue television reception.

Presently, there are no limits for radio noise due to spark discharges, which may occur at bad contacts or on the surface of polluted insulators, to protect radio reception in the UHF band (around 470 MHz to 950 MHz) for digital television broadcasting. The characteristics of spark discharges in the UHF band are not fully understood yet. Furthermore, digital television systems employ error-correction functions, and the true effects of spark discharges to image quality are consequently not quite known.

The values of limits given as examples are calculated to provide a reasonable degree of protection to the reception of e.g. radio broadcasting at the edges of the recognized service areas of the appropriate transmitters in the a.m. radio frequency bands, in the least favourable conditions likely to be generally encountered. These limits are intended to provide guidance at the planning stage of the line and national standards or other specifications against which the performance of the line may be checked after construction and during its useful life.

Recommendations are made on the design, routing, construction and maintenance of the lines and equipment forming part of the power distribution system to minimize interference and it is hoped that this document will aid other radio services in the consideration of the problems of interference.

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# RADIO INTERFERENCE CHARACTERISTICS OF OVERHEAD POWER LINES AND HIGH-VOLTAGE EQUIPMENT –

## Part 1: Description of phenomena

## 1 Scope

This part of CISPR 18, which is a Technical Report, applies to radio noise from overhead power lines, associated equipment, and high-voltage equipment which may cause interference to radio reception. The scope of this document includes the causes, measurement and effects of radio interference, design aspects in relation to this interference, methods and examples for establishing limits and prediction of tolerable levels of interference from high voltage overhead power lines and associated equipment, to the reception of radio signals and services.

The frequency range covered is 0,15 MHz to 3 GHz.

Radio frequency interference caused by the pantograph of overhead railway traction systems is not considered in this document.

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## 2 Normative references

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

IEC 60050-161, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

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

CISPR TR 18-2:__ [1], *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 2: Methods of measurement and procedure for determining limits*

ISO IEC Guide 99, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

NOTE Informative references are listed in the Bibliography.

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-161 and the ISO IEC Guide 99 apply.

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[1] Under preparation. Stage at the time of publication: CISPR/RPUB 18-2:2017.

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

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

# 4 Radio noise from HV AC overhead power lines

## 4.1 General

Radio noise from high voltage alternating current (HVAC), which is to say above 1 kV, overhead power lines may be generated over a wide band of frequencies by

a) corona discharges in the air at the surfaces of conductors, insulator assemblies and hardware;

b) discharges and sparking at highly stressed areas of insulators;

c) sparking at loose or imperfect contacts and at defects in hardware (cracks, rust).

The sources of a) and b) are usually distributed along the length of the line, but source c) is usually local. For lines operating above about 100 kV, the electric stress in the air at the surface of conductors and hardware can cause corona discharges. Sparking at bad contacts or broken or cracked insulators can give rise to local sources of radio noise. High voltage apparatus in substations may also generate radio noise which can be propagated along the overhead lines.

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If the field strength of the radio noise at the antennas used for radio reception is too high, it can cause degradation of the quality and performance of the respective radio communication or broadcast service and application.

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The generation of radio noise is affected by weather conditions, for example, conductor corona is more likely to occur in wet weather because of the water droplets which form on the conductors whereas, under these conditions, bad contacts can become bridged with water droplets and the generation of radio noise, by this process, ceases. Consequently, loose or imperfect contacts are more likely to spark in dry weather conditions. Dry, clean insulators may cause interference in fair weather, but prolonged sparking on the surfaces of insulators is more likely to occur when they are polluted, particularly during wet, foggy or icy conditions.

For interference-free reception of radio signals, it is important that a sufficiently high ratio is available at the input to the receiver between the level of the wanted signal and the level of the unwanted radio noise. Interference may therefore be experienced when the signal strength is low and the weather conditions are conducive to the generation of radio noise.

Unlike analogue radio reception, to realize interference-free reception of digital signals, it is important to keep the bit error rate (BER, BER used to evaluate digital communication quality) below a certain value, for example, below around $10^{-2}$ in the front of Viterbi decoder in case of a ISDB-T system. In this regard, a BER of around $10^{-2}$ in the front of Viterbi decoder assures a BER below $10^{-8}$ at the input of a display by error-correction function, which is commonly employed in modern digital communication systems.

When investigating radio noise it should be borne in mind that the local field may be caused by a distant source or sources as the noise may propagate along the line without substantial losses, over a considerable distance.

## 4.2 Physical aspects of radio noise

### 4.2.1 Mechanism of formation of a noise field

#### 4.2.1.1 General

Corona discharges on conductors, insulators or line hardware or sparking at bad contacts can be the source of radio noise as they inject current pulses into the line conductors. These propagate along the conductors in both directions from the injection point. The various components of the frequency spectrum of these pulses have different effects.

In the frequency range 0,15 MHz to a few megahertz, the noise is largely the result of the effect of propagation along the line. Direct electromagnetic radiation from the pulse sources themselves does not materially contribute to the noise level. In this case, the wavelength is long in comparison with the clearances of the conductors and thus the line is not an efficient radiator. However, associated with each spectral voltage and current component, an electric and a magnetic field propagate along the line. In view of the relatively low attenuation of this propagation, the noise field is determined by the aggregation of the effects of all the discharges spread over many kilometres along the line on either side of the reception point. It should be noted that close to the line the guided field predominates, whereas further from the line the radiated field predominates. The changeover is not abrupt and the phenomenon is not well known. This effect is not important at low frequencies but is apparent at medium frequencies.

However, for spectral components above 30 MHz where the wavelengths are close to or less than the clearance of the line conductors, the noise effects can be largely explained by antenna radiation theory applied to the source of noise, as there is no material propagation along the line.

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It should be appreciated, however, that 30 MHz does not represent a clear dividing line between the two different mechanisms producing noise fields.

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#### 4.2.1.2 Longitudinal propagation

In the case of a single conductor line mounted above the ground, there is a simultaneous propagation of a voltage wave $U(t)$ and a current wave $I(t)$.

For a given frequency, the two quantities are related by the expression $U(\omega) = Z(\omega) \times I(\omega)$ where $Z$, also a function of $\omega$, is the surge impedance of the line.

During propagation the waves are attenuated by a common coefficient $\alpha$ where:

$$U_x = U_0 e^{-\alpha x}$$

$$I_x = I_0 e^{-\alpha x}$$

where

$U_0$ and $I_0$ are the amplitudes at the source, and

$x$ is the distance of propagation along the line.

In case of multi-phase lines, experience shows that any system of voltages or currents becomes distorted in propagation, that is to say, the attenuation varies with the distance propagated and it differs for each conductor. Theory of propagation and actual measurements on power lines have shown that noise voltages on the phase conductors can be considered as being made up of a number of "modes", each one having components on every conductor. One mode propagates between all conductors in parallel and earth. The others propagate

between conductors. Each mode has its own different propagation attenuation. The complete theory of modal propagation is complex and involves matrix equations outside the scope of this document. Reference is made here to CIGRÉ and other published works. It is important to note that the attenuation of the conductor-to-earth mode propagation is fairly high, that is to say 2 dB/km to 4 dB/km, while the attenuation of the various conductor-to-conductor modes is a small fraction of 1 dB/km at a frequency of 0,5 MHz.

#### 4.2.1.3 Electromagnetic field

The radio noise voltages and currents propagating along the line produce an associated propagating electromagnetic field near the line.

It should be noted here that in free space the electric and magnetic components of the field associated with radiated electromagnetic waves are at right angles both to each other and to the direction of propagation. The ratio of their amplitudes represents a constant value:

$$\frac{E_{(\mathrm{V/m})}}{H_{(\mathrm{A/m})}} = 377\,\Omega$$

and is called the intrinsic impedance or impedance of free space.

On the other hand, the fields near the line are related to the radio frequency voltages and currents propagating along the line and their ratio depends on the surge impedance of the line for the various modes. Furthermore, the directions of the electric and magnetic field components differ from those for radiated fields in free space as they are largely determined by the geometrical arrangements of the line conductors. The matter is further complicated by the fact that soil conditions affect differently the mirror image in the ground of the electric and magnetic field components, respectively.

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The electric field strength $E(y)$ at ground level of a single conductor line, which is the vertical component of the total electric field strength, can be predicted by the following empirical equation that has, in a lot of cases, proven to give a good approximation:

$$E(y) = 120\ I \frac{h}{h^2 + y^2}$$

where

$I$ is the radio noise current, in A, propagating in the conductor;

$h$ is the height above ground, in m, of the conductor;

$y$ is the lateral distance, in m, from a point at ground level directly under the conductor to the measuring point; and

$E$ is the electric field strength, in V/m.

Furthermore, for an infinitely long single conductor line, the induction zone, or near field, has the same simple ratio of electric and magnetic field strength as the far field from a radio transmitter, that is to say 377 Ω, and this is approximately true for all values of ground conductivity.

In the case of a multi-phase line, the total electric field strength is the vector sum of the individual field strength components associated with each phase conductor. A more comprehensive treatment, together with practical methods of assessing the electromagnetic field, is discussed in 5.3 of CISPR TR 18-2:__[2]. The equation given above is a simplified version accurate for a distance of $D$ = 20 m and $f$ = 0,5 MHz where $D$ is the direct distance, in

2 Under preparation. Stage at the time of publication: CISPR/RPUB 18-2:2017.

m, between the measuring antenna and the nearest conductor of the line, and $f$ is the measurement frequency. For conventional power transmission lines (i.e. with a conductor height above ground which is less than 15 m), this direct distance $D$ approximately corresponds to a lateral distance $y$ of 15 m. For a wider range of $D$ and $f$, it would be necessary to take into account all the parameters affecting the equation.

#### 4.2.1.4 Aggregation effect

In the case of uniformly distributed noise sources, the field strength generated by a unit length of a phase conductor can be expressed at any point along the line as a function of the longitudinal distance $x$ and the lateral distance $y$, that is to say, $E(y,x)$. At a given lateral distance of $y$,

$$E(y,x) = E_0(y)e^{-\alpha x}$$

The random pulses on a long line with uniformly distributed noise sources combine together to form the total field. The manner in which they combine is not unanimously agreed upon. Some investigators consider that they combine quadratically:

$$E^2(y) = 2\int_0^{\infty} E_0^2(y)\mathrm{e}^{-2\alpha x}\mathrm{d}x$$

or

$$E(y) = \frac{E_0}{\sqrt{\alpha}}.$$

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Other investigators believe that, if a quasi-peak detector is used to measure the field strength, the individual pulses do not add and others have obtained results between the two extremes. This disagreement is only important in analytical prediction methods, the results obtained by the different methods vary by only 1 dB or 2 dB.

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In case of multi-phase lines, the calculation follows the sample principle but is complicated by the presence of several modes, each mode having a different attenuation coefficient. A more detailed discussion, with examples of calculation, is given in Clause 6.

### 4.2.2 Definition of noise

The instantaneous value of the noise varies continuously and in a random manner, but its average power level over a sufficiently long period, for example, 1 s, gives a stationary random quantity which can be measured. Another quantity suitable for measurement is the peak or some weighted peak value of the noise level.

A noise measuring instrument is basically a tuneable selective and sensitive voltmeter with a specified pass-band. When connecting to a suitable rod or loop antenna and properly calibrated, it can measure the electric or magnetic component of the noise field. For measurements of the magnetic component of the noise field in the frequency range up to 30 MHz, normally a loop antenna is used. For measurements of the electric component of the noise field in the frequency range above 30 MHz, use of a biconical antenna is recommended.

Depending on the design of the measuring receiver, the noise level can be measured in terms of RMS, peak or quasi-peak values. The RMS value defines the noise in terms of energy. Many types of noise from electrical equipment, as well as noise due to power-line corona, consist of a succession of short pulses with approximately stable repetition frequencies. In such cases, the nuisance effect of the noise can be realistically indicated by a quasi-peak type of voltmeter rather than by the RMS type. The quasi-peak value is obtained from a circuit which includes a diode and a capacitor with relatively short charge and long discharge time constants. The voltage on the capacitor floats at a value somewhat below the peak value and depends on the repetition rate, that is to say a weighting feature is included in the response.