TR CISPR 18-3

Edition 2.0 2010-06

TECHNICAL REPORT

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

Radio interference characteristics of overhead power lines and high-voltage equipment –
Part 3: Code of practice for minimizing the generation of radio noise

TR CISPR 18-3:2010(E)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

- Catalogue of IEC publications: www.iec.ch/searchpub
  The IEC on-line Catalogue enables you to search by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, withdrawn and replaced publications.
- IEC Just Published: www.iec.ch/online_news/justpub
  Stay up to date on all new IEC publications. Just Published details twice a month all new publications released. Available on-line and also by email.
- Electropedia: www.electropedia.org
  The world's leading online dictionary of electronic and electrical terms containing more than 20 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary online.
- Customer Service Centre: www.iec.ch/webstore/custserv
  If you wish to give us your feedback on this publication or need further assistance, please visit the Customer Service Centre FAQ or contact us:

Email: csc@iec.ch
Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00

TR CISPR 18-3

Edition 2.0 2010-06

TECHNICAL REPORT

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

Radio interference characteristics of overhead power lines and high-voltage equipment – Part 3: Code of practice for minimizing the generation of radio noise

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PRICE CODE X

ICS 33.100.01

ISBN 978-2-88912-018-5

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION
INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

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

Part 3: Code of practice for minimizing the generation of radio noise

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

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 18-3, 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 second edition cancels and replaces the first edition published in 1986. It is a technical revision.

This edition includes the following significant technical changes with respect to the previous edition: while the first edition of CISPR 18-3 only covered recommendations for minimizing the generation of radio noise emanating from high-voltage (HV) power systems, this second edition now also covers a new clause providing formulae for predetermination of the radio noise field strength levels from HV overhead power lines with large conductor bundles. Furthermore, Annex A was accomplished with a collation of predetermination formulae developed and used by several institutions around the world. The tables also contain typical examples of radio noise field strength levels obtained during some measurements campaigns at several HV overhead power line constructions.

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

DTR	Report on voting
CISPR/B/495/DTR	CISPR/B/503/RVC

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 technical report 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

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

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

INTRODUCTION

This technical report forms the third of a three-part publication dealing with radio noise generated by electrical power transmission and distribution facilities (overhead lines and substations). It contains recommendations for minimizing the generation of radio noise emanating from high-voltage (HV) power systems which include, but are not restricted to, HVAC or HVDC overhead power lines, HVAC substations and HVDC converter stations, hardware, etc., in order to promoting protection of radio reception.

The recommendations given in this part 3 of the CISPR 18 series are intended to be a useful aid to engineers involved in design, erection and maintenance of overhead lines and HV stations and also to anyone concerned with checking the radio noise performance of a line to ensure satisfactory protection of radio reception. Information on the physical phenomena involved in the generation of electromagnetic noise fields is found in CISPR/TR 18-1. It also includes the main properties of such fields and their numerical values. CISPR/TR 18-2 contains recommendations for methods of measurement for use on-site or in a laboratory. It furthermore recommends procedures for determination of limits for the radio noise from HV power systems.

This second edition of CISPR 18-3 was adapted to the modern structure and content of technical reports issued by IEC. The first edition of CISPR 18-3 underwent thorough edition and adaptation to modern terminology. Furthermore its content was adjusted such as to allow for use of the lateral distance *y* for the conduction of measurements in the field.

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

The main content of this technical report is based on CISPR Rec. No. 57 given below:

CISPR RECOMMENDATION No. 57

CODE OF PRACTICE FOR MINIMIZING THE GENERATION OF RADIO NOISE

The CISPR

CONSIDERING

a) that the radiation of electromagnetic energy from overhead power lines causes interference to sound and television broadcasting,
b) that the level of this noise may be reduced by the design and lay-out of a line,
c) that when defects cause unusually high levels of interference there is need to detect and locate these faults,

RECOMMENDS

That the latest edition of CISPR Publication 18-3, including amendments, be used as guide for minimizing the generation of radio noise caused by overhead power lines.

CISPR/TR 18-1 describes the main properties of the physical phenomena involved in the production of disturbing electromagnetic fields by overhead lines and provides numerical values of such fields.

In CISPR/TR 18-2 methods of measurement and procedures for determining limits of such radio interference are recommended.

This CISPR/TR 18-3 forms a "Code of Practice" to reduce to a minimum the production of radio noise by power lines and equipment.

It provides information which is advisable to follow both when designing various fittings and components and when stringing the conductors and installing the hardware of the line.

It also describes methods of detecting and locating defects resulting in unusually high interference levels, and provides prevention and correction procedures that are generally simple to implement.

Lastly, this Part 3 provides formulae for predicting the most probable radio noise field of a line for various weather conditions, insofar as radio noise is caused by conductor corona.

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

Part 3: Code of practice for minimizing the generation of radio noise

1 Scope

This part of CISPR 18, which is a technical report, applies to radio noise from overhead power lines and high-voltage equipment which may cause interference to radio reception, excluding the fields from power line carrier signals.

The frequency range covered is 0,15 MHz to 300 MHz.

2 Normative references

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

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

CISPR/TR 18-1:2010, *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 1: Description of phenomena*

CISPR/TR 18-2:2010, *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 the IEC 60050-161 and the ISO/IEC Guide 99 apply.

4 Practical design of overhead power lines and associated equipment in order to control interference to radio broadcast sound and television reception

4.1 Overview

This clause provides guidance on the techniques that may be applied during the design, construction and operation of high voltage overhead power lines and associated equipment in order to keep the various types of radio noise described in this publication within acceptable levels.

4.2 Corona on conductors

During line design, consideration should be given to the geometric parameters of the line, in order to ensure that radio noise due to conductor corona will not exceed a specified acceptable level. The most important parameters are conductor diameter and number of conductors per phase. Others that could be varied, such as distance between phases, height of conductors above ground or spacing of sub-conductors in the bundle, have a smaller effect. In practice they are usually determined by mechanical or insulation requirements.

The quantitative laws that determine the level of radio noise caused by conductor corona are discussed in 4.3 of CISPR/TR 18-1, and in Clause 7 below. These laws normally apply to both stranded and smooth conductors, since the surface unevenness caused by stranding does not, in general, substantially change the noise level, especially when conductors are damp or wet. The existence of scratched or broken strands or deposits of extraneous substances such as dirt or insects on the surface, on the other hand, may lead to severe localised corona discharges, due to high local voltage gradients. This may considerably increase the noise level of the line. For these reasons it is necessary to avoid damage to the conductor surface during construction. It should be handled with great care in transportation and erection and suitable techniques should be used to avoid contact of the conductor with the ground or other objects during stringing. It is also advisable to avoid external greasing of the conductor for protection during transportation and tensioning; when the conductor is loaded, the increase in temperature, especially in hot weather, will cause this grease to run to the outside, gathering dirt and leading to areas with high local gradient and consequent radio noise. When the steel core or inside layers are greased for corrosion protection, a type of grease should be selected that will not migrate to the surface of the conductor even at the highest temperature.

4.3 Corona on metal hardware

Radio noise due to corona on metal hardware, such as suspension clamps, dead-end clamps, yokes, guard rings, horns, spacers, etc., can be controlled. Appropriate shapes and dimensions may be specified during the design stage in order to avoid points of high voltage gradient. All edges and corners should be well rounded, bolt heads should be rounded or shielded and sharp points and protrusions should be avoided. It is also important that the protective galvanized finish on hardware be smooth, particularly at points of maximum voltage gradient.

Guard devices are sometimes installed to protect an insulator string from the destructive effects of a power arc and to improve the distribution of the potential along the string. They also contribute to the reduction of the level of radio noise from the conductor clamps, since they screen sharp points or protrusions on the clamps. The type and dimensions of the guard devices should be chosen in such a way that they do not themselves produce radio noise. For example, the use of simple horns should be avoided at voltages exceeding about 150 kV, and the diameter of tubes forming guard rings should be sufficiently large to ensure that no corona occurs during rain.

Present knowledge seems to indicate, however, that it may be relatively difficult to design guard rings suitable for rainy conditions, even if they are made of multiple tubes. In which case, it may be necessary to devise special arrangements for the yoke so that the string is screened directly by the conductor bundle and is protected from power arcs by suitable devices on the sub-conductors of the bundle.

As in the case of conductors, it is important to avoid damage to the hardware during manufacture, transportation, construction and maintenance by handling them with great care at all times.

4.4 Surface discharges on insulators

4.4.1 Clean or slightly polluted insulators

The radio noise produced by these insulators under dry conditions can be controlled by:

– the use of insulators of suitable design, especially as regards their geometry and the characteristics of the material at the more critical areas, or
– the use of guard devices designed to improve the distribution of voltage on the surface of the insulator or along the insulator string.

In insulator design, the use of conducting glaze, for example, improves the distribution of the surface voltage gradient on the insulator. In the design of a guard device, a metal ring as close as possible to the insulator, or to at least the first two or three insulators at the line end of an insulator string, may considerably improve the voltage distribution on the insulator or along the insulator string and reduce radio noise. The ring, however, shall remain compatible with other requirements such as insulation withstand, protection of the insulators from power arcs, screening of the clamps, etc. (see 4.3).

The radio noise produced in damp weather, fog or rain is usually more difficult to control than the noise under dry conditions. It is, however, seldom a critical factor in line design, since the increase in noise due to water droplets on the insulators is usually less important than the corresponding increase in noise produced by the conductors.

4.4.2 Very polluted insulators

Under dry conditions, in addition to the phenomena that cause noise on a clean insulator, other phenomena of the corona type may occur due to surface unevenness created by pollution deposits, as mentioned in 6.1 of CISPR/TR 18-1. Under these conditions even careful design of the various parts of an insulator may be of little benefit. Stress control devices suitable for improving the voltage distribution on the insulator or along the insulator string, however, may considerably improve the radio noise performance.

When the polluted insulator surface is wet, radio noise is generated by sparks across the dry bands, created by the leakage currents, as discussed in 6.1 of CISPR/TR 18-1. Occasionally, this noise has very high frequency components. It may affect both sound and television reception and is difficult to control. The only practical remedy is to limit the leakage current activity on the surface of the polluted insulator. This may be achieved by:

a) diminishing the voltage stress on the insulator – for example by using a longer surface creepage path than is necessary for electrical withstand;
b) using special types of insulators such as those made of organic material or coated with semi-conducting glaze, or designs with a longer creepage path such as fog type units, special shapes, etc.;
c) coating the insulators with silicone grease.

4.5 Spark and microsparks due to bad contacts, commutation effects

Remedial measures for eliminating or reducing these types of radio noise are described in Clause 5 below and in 8.4 of CISPR/TR 18-1 respectively.

4.6 Defects on power lines and associated equipment in service

Even if all possible precautions have been taken during design and construction of a power line or substation to keep radio noise within acceptable limits, defects may occasionally occur during operation, resulting in intolerable noise. This may be caused by breakage of strands on the conductors, damage to clamps or insulators or accumulation of pollution on conductors and insulators. In general, these defects shall be eliminated in order that the power system may operate properly, whether or not they are sources of radio noise. In fact, the occasional noise caused by such defects may result in detection and location of potential power system faults.

These abnormal noise sources may be located by various instruments such as radio noise measuring sets, television receivers or ultrasonic and optical detectors. Location will often be easier when the noise affects television reception, since at very high frequencies longitudinal attenuation along the line is very high. When only low and medium frequency radio broadcasts are affected, location of the noise source may require the recording of the longitudinal attenuation of the radio noise field strength, combined with optical, ultrasonic or ultraviolet devices, as discussed in Clause 5.

5 Methods of prediction of the reference level of an overhead line

5.1 General

This publication has been written to provide the engineer in the field with the theoretical and practical background necessary to deal with radio interference problems. Technical aspects have been dealt with in part 1 and many of the aspects discussed are dealt with in this clause in a simplified manner to bring together the theoretical and practical issues.

The reference level of a line is the strength of the radio noise field at a reference frequency of 500 kHz and at a direct distance of 20 m from the nearest conductor of the line. Where the voltage gradient in the air at the surfaces of the conductors of a normal line is greater than about 12 kV/cm to 14 kV/cm, depending on conductor diameter, the radio noise performance of the line is determined by the performance of the conductors. The number and diameter of the conductors per phase of a proposed line are often decided by the current-carrying capacity required or by economic considerations and usually a prediction of the reference level is required for a particular weather condition. If a line is designed with the conductors at a high surface gradient very little can be done to reduce the noise level once the line has been constructed.

Figure B.14 of Annex B of CISPR/TR 18-1 gives the correction to be applied to a radio noise level relating to a measurement frequency other than 500 kHz.

Where the voltage gradient in the air at the surfaces of the conductors of a line is less than about 12 kV/cm, the radio noise level is usually determined by the insulators and hardware. In this case the radio noise performance of the line is inherently good and it is usually desirable to preserve this good quality by selecting insulators and hardware of a matching quality. Most of the methods of prediction or predetermination are concerned with the conductor noise and do not apply to lines where the conductors are at a low surface gradient. None of the methods applies to sparking sources at loose or imperfect contacts.

5.2 Correlation of data given elsewhere in this publication

This clause contains information about the correlation of the radio noise voltage at the line and the resulting radio noise field strength at ground level at a certain lateral or direct distance slant to the respective line.

a) Methods relating to noise from conductors

   Subclause 5.3 of CISPR/TR 18-1 gives a survey of methods of prediction or predetermination, both analytical or semi-empirical and empirical or comparative. The analytical method relies on the results of measurements carried out on a short length of sample conductor in a test cage and involves highly complex analyses. The sample conductor can be tested with any desired surface condition and the radio noise voltage measured by a circuit given in 4.5 of CISPR/TR 18-2. However, for a.c. lines, a reliable prediction of the reference level due to conductor corona can be calculated only from the wet test since in this case the number of individual corona sources per unit length is sufficiently high to represent a statistically satisfactory sample. For d.c. lines, reference should be made to 8.2 of CISPR/TR 18-1 for the calculation of the noise level.

   The simple comparative formulae referred to in 5.3 of CISPR/TR 18-1 rely on the results of radio noise field strength measurement carried out on an existing line of similar design. These formulae take into account the effects of any difference between the reference and proposed lines such as the differences in surface voltage gradient or conductor diameter. If the design of the reference and the proposed lines are similar and the operating conditions, such as air pollution, etc., are also similar a fairly accurate prediction may be obtained of the reference level to be expected from the proposed line due to conductor corona. The effects of weather may also be determined by taking measurements on the reference line in a variety of weather conditions.

In 5.4 and Annex B of CISPR/TR 18-1 is given a catalogue of radio noise field strength profiles resulting from conductor corona for certain designs of single circuit overhead line. The profiles are correct when the value of the voltage gradient in the air at the surfaces of the conductors of the lines are sufficiently high to produce radio noise and the values of the field strength, at a measurement frequency of 500 kHz, are given for both heavy rain and average fair weather conditions; the heavy rain conditions producing a higher field strength of between 17 dB and 25 dB. The profiles show the attenuation of the field with distance normal to the lines for distances out to 150 m.

b) Method relating to noise from insulators and/or fittings

Subclause 6.2 of CISPR/TR 18-1 gives a correlation between the radio noise voltage generated by a hardware or component of a line, when measured in accordance with the procedure given in 4.5 of CISPR/TR 18-2, and the level of the reference field. This correlation applies where the line has a single noise source, for example a broken insulator, or where multiple sources are uniformly distributed along the line. The method, which includes a semi-empirical formula, is particularly useful where the conductors of a proposed line are to operate at a low surface gradient and a prediction is required of the reference level to be expected from the insulators of the line. When the measurement procedure given in 4.5 of CISPR/TR 18-2 is carried out on insulators they are usually in a clean and dry condition, since this condition is normally specified, but the procedure is not restricted to measurements on clean and dry objects and specially polluted sample insulators could be tested when damp and when dry and the results inserted into the formula to predict the reference level of a proposed line.

c) Methods relating to aggregate noise from the conductors, insulators and/or hardware.

Subclause 5.2 of CISPR/TR 18-1 gives information on the use of test lines. Where conditions relating to a new design of line are such that they cannot be related to data available from an existing line the expected performance is sometimes studied on a relatively short test line. Such test line studies are particularly useful when a new system, for operation at a much higher voltage than hitherto, is in the planning stage. The radio noise performance of the experimental line is monitored in a range of weather and atmospheric conditions so that the performance of the proposed line can be assessed under the conditions which it will experience in service. This could also include the effects of insulator pollution. Other important data, such as corona loss and acoustic noise performance, can also be obtained from the test line at the same time.

In 5.4 of CISPR/TR 18-2 a method is given whereby the reference level of a line may be found which will protect a given broadcast signal strength at a given distance from the line for 80 % of the time with 80 % confidence.

5.3 CIGRÉ formula

A simple direct formula has also been evolved for predicting the level of the radio noise field strength to be expected from the conductors of a line. The formula, which is empirically based, gives the most probable level to be expected from aged conductors in fair weather at a direct distance D_0 of 20 m from the nearest conductor at a measurement frequency of 500 kHz. The formula is derived from lines operating at voltages between 200 kV and 765 kV and at maximum voltage gradients between 12 kV/cm and 20 kV/cm. Strictly, the formula gives the noise from one phase conductor or bundle of a line and the effects of the other conductors may be taken into account by a summation process; however, for a number of designs of lines within these ranges, it is found that only a small error is introduced if only the conductor producing the highest noise at the measuring point of a three-phase line is considered; usually this is the nearest conductor but not necessarily so in all cases.

The formula is

$$E = 3{,}5\ g_{max} + 12\ r - 30, \qquad \text{in dB}(\mu\text{V/m})$$

where

E is the level of the radio noise field strength in dB(μV/m) at a direct distance D_0 of 20 m from nearest conductor of proposed line;

g_{max} is the maximum gradient of the r.m.s. voltage at the conductor surface, in kV/cm;

r is the radius of conductor or sub-conductor, in cm.

This matter is considered in more detail in Annex A.

5.4 Determination of 80 % level

The 80 % level for a line may be predicted by calculation [2, 3]* or, if the line exists, the 80 % level may be determined with a high degree of confidence, by measurement. Methods of determining the 80 % level are as follows:

1) for an existing line the 80 % level may be determined, with a high degree of confidence, from the all-weather distribution curve obtained by measurements made over a period of one year.
2) if the all-weather distribution curve is not available, or in the case of a proposed line, the results of measurements made one line of similar design in a similar climate and pollution environment could be used.
3) from the figures mentioned in 4.3.4 of CISPR/TR 18-1 it is seen that, on average, the 80 % level for a line is 10 dB greater than the 50 % level. Therefore, if the 50 % level is known the 80 % level may be estimated.
4) the 80 % level may be predicted by adding 5 dB to 15 dB, depending on the climate, to the fair-weather level estimated from the simple formula given in 5.3 above.

5.5 Conclusions

The particular method of prediction to use in the case of a particular proposed line will depend on whether the interest is in conductor corona or noise due to insulators and/or hardware that is whether the conductors are to operate at a voltage gradient greater than about 14 kV/cm or less than about 12 kV/cm. For voltage gradients in between these values both the conductors and the insulators may contribute to the noise level of the proposed line.

The simple comparative formula referred to in item a) of 5.2, the catalogue of radio noise field strength profiles referred to also in item a) of 5.2 and the CIGRÉ formula given in 5.3 are all simple to use and, provided they are used within their inherent limitations, they should give reasonably accurate indications of the reference level to be expected from the conductors of a proposed line. It should be borne in mind that owing to the variable nature of radio noise and its dependency on the effects of weather, atmospheric conditions, pollution, etc., it is often difficult to measure the reference level of a line with any high degree of accuracy and reproducibility.

The method referred to in item b) of 5.2 relating to noise from insulators and/or hardware has not, as yet, become established practice for the case of specially polluted test insulators but the method would appear to have promise for this case. If a test line, referred to in item c) of 5.2, is available, together with the time required to carry out experimental work, the likely reference level from a proposed line may be obtained with a good degree of accuracy for the particular conductor, insulators and hardware proposed.

---

* The figures in square brackets refer to the Bibliography.

6 Preventive and remedial measures to minimize radio noise generated by bad contacts and their detection and location

6.1 General

Radio noise generated by sparking at bad, that is loose or imperfect, contacts occurs mainly in dry weather since in wet weather the comparatively small gaps involved usually became bridged with moisture.

6.2 Preventive and remedial measures

When constructing high voltage equipment it is important

1) to ensure that all fixing bolts are securely tightened, and
2) to bond conducting elements, as far as is possible, either to earth or conductor potential.

On distribution lines, bonding adjacent metal surfaces is important but bonding to earth or conductor potential is not required for spark suppression. If bonding to one side is not possible (for example at the pin and clevis, or ball and socket, couplings of an insulator string), the adjacent conducting elements should have good metal-to-metal contact and the whole assembly should be well insulated from other metallic parts of the equipment. It should be borne in mind that even when equipment is new, galvanized metallic parts can have a corrosion coating of zinc carbonate. When the surfaces have weathered, additional oxides and sulphides may be present and an imperfect contact may result leading to the possibility of gap-type discharges. The phenomenon may occur when suspension insulator strings have inadequate mechanical loading.

The following preventive and remedial measures have been found to be effective:

a) Conductive grease and paste

   A quick and economical method is the application of conductive grease to the socket or clevis area of insulators. This is a temporary cure, however, and it is necessary to re-apply the grease at a later date. The use of a copper paste, instead of conductive grease, promises to be a more lasting remedy but care shall be taken to ensure that the grease or paste does not find its way on to an insulating surface.

   Ordinary, non-conductive grease applied to freshly galvanized surfaces will inhibit corrosion.

b) Bonding brush

   The application of a bonding brush, with stainless steel bristles, is a temporary cure, lasting for some three to five years, by providing metal-to-metal contact in the pin and clevis, or ball and socket, area.

c) Bonding clip

   Where pin and clevis type insulators are used, bonding clips can easily be installed in the pin and clevis area. It is especially important that these be installed in the conductor clamp connection with the line end insulator. There are several types of clip suitable for insertion between ball and socket which maintain sufficient pressure to break down the oxide film.

d) Permanent bonding

   The best results are likely to be obtained with a permanent flexible bond across each individual metallic link of the insulator string, together with bonds from the earth end insulator to the cross-arm and from the conductor clamp to the line end insulator. The bonds should consists of stranded stainless steel or copper cable and can either be welded or fastened by screws. The cable should have a plastic covering to prevent bird caging of broken strands.

e) Metal weights for insulator strings with inadequate mechanical loading

In order to ensure good contact between the caps and pins of adjacent insulator units, the strings should be loaded with metal weights which are well-rounded to prevent corona discharges.

f) Spring and plastic washers

If a wooden construction is used there is some merit in using spring or plastic washers. The spring washers are capable of preventing loose hardware on poles and cross-arms due to wood shrinkage. A plastic washer of acetate or nylon also improves tightness of the nuts. Where these "shakeproof"-type nuts or plastic washers are used, care should be taken to ensure that there are no insulating gaps between metallic parts. Such a washer is generally used only between a nut and a wood pole or arm.

g) Single insulator

The use of a single insulator has the advantage of having fewer possible radio noise sources.

h) Pin-type insulators with conducting glaze

With pin-type insulators, sparking may occur on the surface where the conductor rests in the top groove and at the tie-wire or stirrups in the side groove of the insulator. This problem may be overcome by using conductive paints or metallization of the insulator surface in the area of contact. These metallizing agents are effective only if applied together with the glaze during manufacture of the insulator. In the case of pin-type insulators, if the pin screws directly into a threaded hole in the porcelain, the porcelain threads should be treated with conductive paint. As an alternative, a threaded metal insert can be cemented into the pin-hole; although the best solution is to purchase insulators with the pin-hole glazed during manufacture.

If a PVC insulated conductor is used, there is a possibility of local discharges occurring at the supporting insulators. These discharges can be avoided by wrapping the PVC with semi-conducting tape. For an 11 kV line, the tape should extend for 600 mm on either side of the insulator.

i) Plastic fasteners and insulated staples

The use of plastic fasteners or insulated staples to secure the earth wire to a wood pole will avoid sparking between the earth wire and its fasteners, particularly if the fasteners became loose or corrosion is present.

6.3 Methods of detecting and locating bad contacts

When bad contacts are present in a power line or substation, the detection and exact location of the radio noise source(s) are more important than the measurement of the resulting field strength. Practical methods for the detection and location of these bad contacts are described below. Measurements and observations should normally be made in fair weather.

Since a high voltage power line and associated equipment is often the source of different radio frequency fields, it is necessary to trace the radio noise by starting at the disturbed receiver. The first step in the investigation is to obtain an aural and/or visual indication of the radio noise, by using a loudspeaker or headphones and an oscilloscope or television receiver.

When tracing the source(s) of radio noise due to bad contacts it is better to observe the noise at the highest frequency perceptible because of the more rapid attenuation along the line. Whilst it is preferable that the apparatus used for tracing should cover the whole radio noise frequency range, few instruments are available that cover this spectrum. Few have been designed specifically for the location of sources of radio noise and, accordingly, it may be necessary to modify commercial apparatus to make it suitable.

The following apparatus will be found useful for locating bad contacts:

a) A general coverage receiver (a.m.) tuneable from at least 500 kHz to 18 MHz.

b) A v.h.f. field strength measuring instrumentation fitted with a two-element broadband antenna and a v.h.f. pre-amplifier. The audio output should be amplified sufficiently to feed a loudspeaker and an oscilloscope.

c) An oscilloscope with sufficient intensity for use in full daylight, when used with a viewing hood, and a sweep frequency of approximately 500 Hz.

d) A u.h.f. field strength measuring instrumentation fitted with two interchangeable Yagi antenna: one array for 500 MHz and the other for 800 MHz. A moderate level audio output is required for a loudspeaker. R.F. pre-amplification is required and i.f. gain control is desirable. The whole assembly should be able to be carried by one man.

e) A small radio frequency detector covering the frequency range m.f. to v.h.f. but without automatic gain control.

f) A small a.m. broadcast radio receiver without manual or automatic gain control and enclosed in a metal box. The receiver antenna can either be telescopic, to allow for variation in r.f. sensitivity, that is to adjust the r.f. gain, or, preferably, a ferrite rod mounted inside the metal box opposite a slot of similar length in the box side. The box is mounted at one end of an insulating tube, a few metres in length and having a diameter of approximately 3 cm to 6 cm. The output of the receiver loudspeaker is directed into the bore of the tube while, at the other end, a microphone is arranged to pick up the noise signal. The microphone output is then fed into an amplifier which feeds headphones or a loudspeaker. This arrangement allows the receiver to be placed near to the source of the disturbance and, with care, can be used even when the radio noise is generated by high voltage equipment.

   The insulating properties of the tube and its length shall be such as to ensure observance of the safety rules appropriate to the system voltage.

g) A sensitive ultrasonic detector with a parabolic reflector. In situations where the noise sources are numerous and are close together, for example in a substation, this can be a particularly useful instrument, but its use is restricted to fair weather conditions. It should be borne in mind that this instrument is also sensitive to corona sources.

A suggested procedure for locating a radio noise source or sources generated by bad contacts is as follows:

i) Using the investigation apparatus, obtain an aural and/or visual identification of the noise signal at the disturbed receiver. Determine the frequency range of the noise by scanning the relevant part of the r.f. spectrum.

ii) If broadband noise appears, use the highest possible frequency for tracking. If it is found, when moving along a power line, that the noise can be detected at progressively higher and higher frequencies, then the source is being approached. In the immediate vicinity of the source the noise signal should be detected throughout most of the broadcast frequency bands. When the higher frequencies start dropping off, the source has been passed. Along the power line nulls may occur, at certain positions and at certain frequencies, due to standing wave patterns. For wood pole lines, a sledge hammer can be useful. If the base of the pole is struck with the hammer, noise due to bad contacts on that particular pole may either increase drastically or disappear temporarily. This assists in localizing the wood pole associated with the noise source.

   A further method for locating bad contacts, particularly in a substation where several joints can be involved, is to direct a very fine water jet at each suspect metal joint in turn. To provide a high degree of insulation, a small volume of water, in a plastic container, is mounted at the end of a long rod or pole of insulating material. Two pipes enter the container, one which terminates in a nozzle to provide the fine water jet and the other which carries compressed air, via a valve, from the ground. The operator on the ground controls the water jet by means of the compressed air. After having located a bad contact, a similar device is often used to inject grease, of suitable consistency, into the defective joint.

iii) If narrow band noise is detected, triangulation will best identify the source. Even here, however, at the source's location, the sparking noise will be detected over a broad range to 100 MHz. Narrow band noise may result from gap-type discharge causing resonance in a fitting or component.

iv) If more than one noise signal exists, it may be necessary to use the oscilloscope to distinguish the sources. To determine if a noise source is due to bad contacts (sparking) or corona, the following information may be helpful:

a) oscilloscope or television pictures usually give clear indication;

b) noise above 30 MHz in fair weather is due to sparking;

c) if the noise occurs only in fair weather, it is probably due to sparking;

d) noise due to sparking predominates over corona noise on lines below about 70 kV.

v) If the investigation indicated that the source is in a substation, a radio frequency detector, as described in item e) or a small a.m. portable radio receiver, without automatic gain control, should be used. The receiver should be placed near to the control wiring and earth connection of each item of plant, in turn, so that the wiring may act as an antenna for the noise source.

vi) In the case of a power line, when the tower involved has been identified, the measuring instrumentation described in item d) should be used to obtain further bearings. The tower should be scanned using both horizontal and vertical polarization of the antenna to determine whether or not the structure contains a source. If no noise field is detected, a further check should be made by tuning some 10 MHz above and below the measurement frequency (a null may occur at a particular frequency).

vii) The last step to pinpoint the source should be carried out with the apparatus described in item f). It may be helpful to scan the insulators, either on the towers or in the substation, to prove that they are noise-free.

viii) Low-level acoustic noise is often associated with sparking and gap-type discharges and the very narrow beam width of a sensitive ultrasonic detector, fitted with a parabolic reflector, will often be found useful in locating the source.

7 Formulae for predetermination of the radio noise field strength produced by large conductor bundles (more than four sub-conductors) and by tubular conductors

7.1 Basic principles

Subclause 5.3 reports a simple formula for the prediction of the radio noise field strength to be expected from the conductors of a line. The formula, which is empirically based, gives the most probable level to be expected from aged conductors in fair weather at a direct distance of 20 m from the nearest conductor at a measurement frequency of 500 kHz. The formula is derived from measurements performed near to lines operating at voltages between 200 kV and 765 kV and at maximum voltage gradients between 12 kV/cm and 20 kV/cm. The measurements were performed on lines with single conductors and conductor bundles up to four sub-conductors.

Methods of predetermination of the radio noise field strength produced by large bundles were developed in the frame of the projects of overhead lines at voltages equal to or higher than 1 000 kV, on the base of measurements on experimental spans or cages. They are based on the so called excitation function approach.

The excitation function approach is based on the fact that the corona currents injected into a multiphase line depend not only on the intrinsic characteristics of the conductor under corona (its gradient, sub-conductor diameter, etc.) but also on the self and mutual capacitance of the multi-conductor system [4]. The radio noise currents are related to the intrinsic corona characteristics of the conductor (named excitation function Γ) through a relationship of the type:

$$|I| = |C| \times |\Gamma| \ / \ (2\ \pi\ \varepsilon_0)$$

where

$|I|$ and $|\Gamma|$ are the vectors of the phase radio noise currents and excitation functions of the conductors;

$|C|$ is the capacitance matrix.

The measurements of the radio noise current in a test configuration of known capacitance (cage or experimental span) allows the determination of the excitation function.

The approach based on the use of the excitation function and analytical methods to calculate the radio noise current propagation allows the predetermination of the radio noise field strengths for line configurations different from the ones tested.

Another important advantage of this approach is that the radio noise current measurement in a cage allows the determination of the excitation function under controlled ambient conditions (artificial rain corresponding to heavy rain) and for different conductor gradients, giving thus stable and reproducible results.

The predetermination methods based on the concept of excitation function was preferred for higher system voltages (voltages equal to or higher than 1 000 kV) where corona is generally more critical and its evaluation can be more accurate. Extensive research in this field has been performed in various countries: Canada (IREQ), Korea (765 kV Project), Italy (1 000 kV Project), Japan (CRIEPI), USA (GE/EPRI-Project UHV, AEP/ASEA, BPA), USSR (1 200 kV Project). These investigations principally consider the case of large bundles and the predetermination formulae given in this publication are the result of the comparison and rationalization of a wide number of experimental results.

For tubular conductors, a similar approach was followed that led to the predetermination formulae for the excitation function given in this publication. The experience gained in this field is much less than with large bundles and consequently the information provided in this publication should only be used as a guide.

The investigations were made with the view of possible application to overhead lines at voltages equal to or higher than 1 000 kV, but the results can be applied to the cases of rigid tubular bus bars in high voltage substations. In this case, the guided field due to the currents injected into the lines connected to the substation is of importance (see 5.7 of CISPR/TR 18-2).

7.2 Calculation of corona radio noise field strengths due to large bundles

7.2.1 Procedure for the predetermination of the radio noise field strength

On the basis of results of a comparative analysis of the various methods proposed in the literature [6 to 13], the following procedure is proposed for the calculation of the radio noise field strength at a given distance from the line for lines with symmetrical bundles and aged conductors:

a) calculation of the excitation function of each phase in heavy rain by means of a semi-empirical formula (see 7.2.2);
b) application of a correction factor to obtain the excitation function in other weather categories (see 7.2.3);
c) determination of the radio noise field strength profile by means of complete or simplified analytical methods based on modal propagation (see 7.2.4).

7.2.2 Calculation of the excitation function in heavy rain

The following formula for the calculation of the excitation function, in dB(μA/m$^{1/2}$), in heavy rain is proposed:

$$\Gamma_{\text{h-r}} = 70 - 585/g + 35 \log(d) - 10 \log(n)$$

where

g is the average of the maximum gradients of the individual sub-conductors (in kV/cm);

d is the diameter of the sub-conductor (in cm);

n is the number of the sub-conductors in the bundle.

This formula gives satisfactory results in case of lines with conductors having a ratio between the sub-conductor spacing s and the sub-conductor diameter d higher than 10 to 15. At smaller s/d ratios, the actual excitation function may prove to be much higher than calculated especially in the case of bundles made of 10 or more sub-conductors.

NOTE A comparison between the different formulae for the predetermination of the excitation function was performed by CIGRÉ WG 36.01 [6]. The formula proposed in this subclause gives the upper envelope of the values that could be obtained with the other formulae and thus gives a conservative evaluation of the excitation function. For this reason the formula should be used only for pre-design purposes and for comparison between different line designs. The design of a line with large conductor bundles would require more accurate evaluation of the excitation function by means of measurements on experimental spans or on corona cages.

7.2.3 Correction factor to evaluate the excitation function in other weather categories

For other weather conditions (light rain, wet conductors, fair weather), different approaches were followed by the various experimenters: some of them give formulae similar in structure to those given for the excitation function in heavy rain, but with different coefficients; some others propose correction factors to be applied to the heavy rain levels, constant or depending on the voltage gradients, bundle configuration and surface conditions of the conductors (in particular new and aged conductors).

As a guidance, if no more precise information is available from tests, the correction factors given in Figure 1 can be applied to the heavy rain excitation function to obtain the 50 % light rain value or the 50 % fair weather value.

If the 80 % all time excitation function value, $\Gamma_{80\,\%}$, is required to apply the indications of limits given in CISPR/TR 18-2, the knowledge of the percentage of the different weather conditions (fair weather, rain, foul weather, etc.) as well as the statistical distributions of the radio noise under each such condition is necessary. Subclause 4.3.4 of CISPR/TR 18-1 shows how the statistical distributions are related to each other. As a rough indication, $\Gamma_{80\,\%}$ could be obtained by subtracting 10 dB to 15 dB from the heavy rain level in temperate climates.

7.2.4 Calculation of the radio noise field strength

7.2.4.1 General

The calculation of the radio noise field strength at a given distance from a three-phase line may be performed starting from the excitation function of each phase by means of analytical methods based on modal propagation analysis. Several computer programs were developed to perform this calculation. They may take into account the discontinuities of the line (change of configuration, interconnection to a substation, etc.). A simplified analytical method applicable to long lines is indicated in Annex B.

To allow a rapid evaluation of the radio noise field strength profiles, instead of the analytical methods, the method given below, which gives an acceptable approximation, can be used.

7.2.4.2 Rapid evaluation of the radio noise field of an overhead line

The evaluation of the radio noise field at a given distance from the line is made by applying to the excitation function a "field correction factor" to obtain the radio noise field strengths of a line of basic design at a given frequency and for a given ground resistivity. The radio noise field for the line under examination is then evaluated by introducing other correction factors to account for the differences between the actual line and that of the basic case.

The evaluation is performed in two steps.

Step 1

The radio noise field strength profile for a line of basic characteristics and under basic conditions (ground resistivity = 100 Ω m; frequency = 0,5 MHz) is evaluated by adding to the excitation function a "field factor". Field factors for three basic phase conductor configurations (flat, triangular and delta configuration) are given in the Figures 2, 3 and 4.

Step 2

The radio noise field strength profile for the actual line under consideration is evaluated by adding to the radio noise field strength of the basic case the correction factors given in Figures 5, 6 and 7 for each of the following parameters:

ρ ground resistivity;

f frequency;

h minimum height above the ground;

S spacing between phases;

d sub-conductor diameter;

n number of sub-conductors in a bundle.

NOTE Consideration of the external phase only does not unduly affect this simplified approach. A constant difference between the excitation functions of the central and external phases is assumed for all configurations: this assumption is not generally verified, but does not give deviations greater than 1 dB to 2 dB. An improvement in accuracy can be by considering the average value of the excitation functions.

7.3 Evaluation of corona radio noise field strength due to large tubular conductors

A procedure analogous to that suggested for the case of large bundle conductors (see 7.2.1) can be followed: the excitation function of each phase in heavy rain is evaluated by means of a semi-empirical formula and a correction factor is then applied to obtain the excitation function in other weather categories.

The following formula for the calculation of the excitation function, in dB(μA/m$^{1/2}$), in heavy rain is proposed:

$$\Gamma_{\text{h-r}} = -121 + 120 \log(g) + 40 \log(d)$$

where

g is the maximum gradient on the conductor (in kV/cm);

d is its diameter (in cm).

As regards the corrections to be applied to obtain the excitation function in other weather categories, the following indications may be useful, until further experience is obtained.

- The excitation function in light rain can be related to the one under heavy rain by means of the correction factor indicated in Figure 8, which is relevant to tubular conductors of 40 cm diameter. For other diameters, one should expect, as for bundle conductors, the correction increases as the diameter increases.
- As large tubular conductors have low electric gradients, the excitation function has insignificant values in fair weather conditions. The 80 % all-weather value of the excitation function thus depends very much on the climatic conditions. In moderate climates, this value may be obtained from the heavy rain value by applying a correction higher than that used for large bundles. For these areas, a correction of 15 dB to 20 dB is suggested until further information is available.

As regards the surface conditions, the following complementary information is available.

Tubular conductors are prone to accumulate more contaminant than bundle conductors the effect of which may be sufficient to alter the excitation function. Tests have shown that the excitation function will not be altered by the effect of pollutants when the conductor is wet. When dry, the presence of solid particles on the surface may increase the radio noise to a value as high as for the same conductor in rain for the highest gradients, especially for low diameter conductors.

The formula given in this subclause may be utilized both for busbars or for line conductors.

In the case of busbars, the per unit length noise current layer I_0 can be obtained from the excitation function Γ by means of the matrix of capacitances of the busbar system (according to the first formula of Annex B). From I_0, the total current I_t injected by the busbar is then obtained. The noise current injected into each one of the *n* lines connected to the substation, *I*, is derived by means of the following relationship (see 5.7.3 of CISPR/TR 18-2):

$$I = I_t / n$$

so that its contribution to the line conductor noise can be evaluated with the criteria indicated in 5.7.4 of CISPR/TR 18-2.

8 Figures

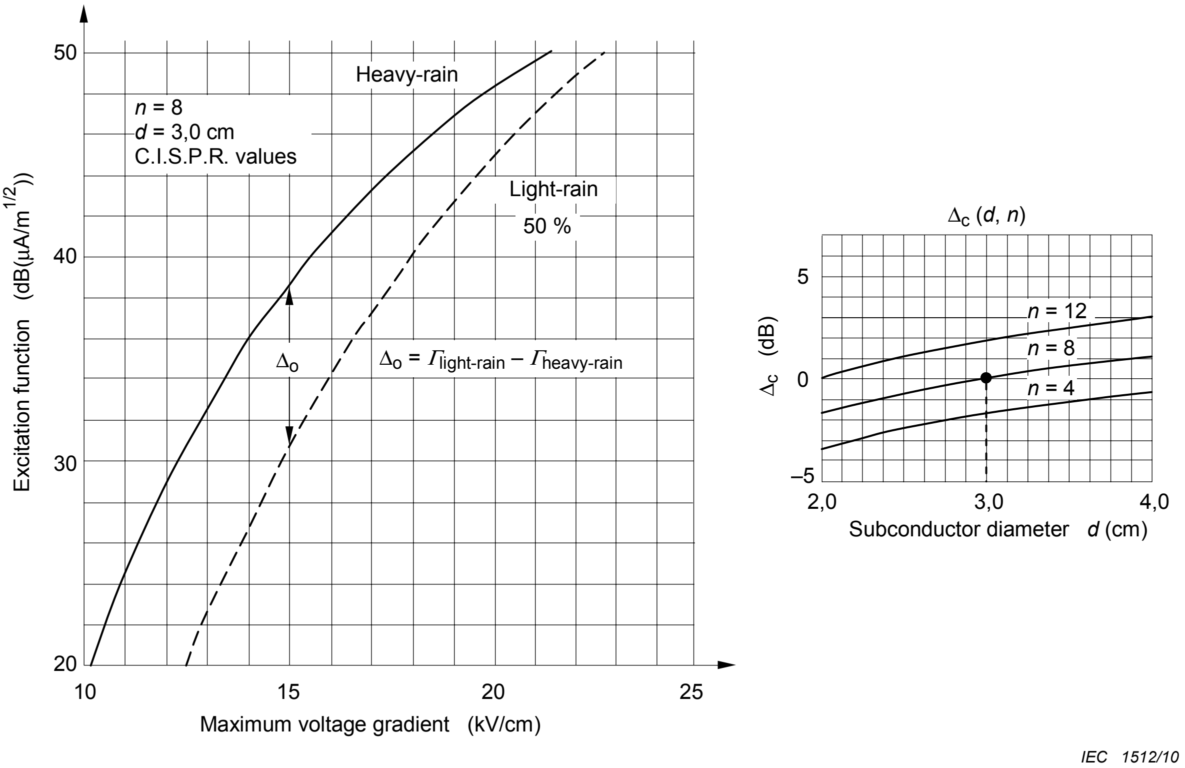


Figure 1 – Bundle conductors

Correction factors to be applied to the heavy rain excitation function to obtain the excitation function for light rain and for all-time weather conditions, as a function of the maximum gradient and number of sub-conductors.

$$\Gamma_{\text{light-rain}} = \Gamma_{\text{heavy-rain}} + \Delta_o + \Delta_c$$

The fair weather excitation function is obtained by subtracting 17 dB from the light rain excitation function.

$$\Gamma_{\text{fair-weather}} = \Gamma_{\text{light-rain}} - 17$$

In temperate climates, the 80 % value of the excitation function Γ for all-time weather conditions can be obtained by subtracting 10 dB to 15 dB from the heavy rain value.

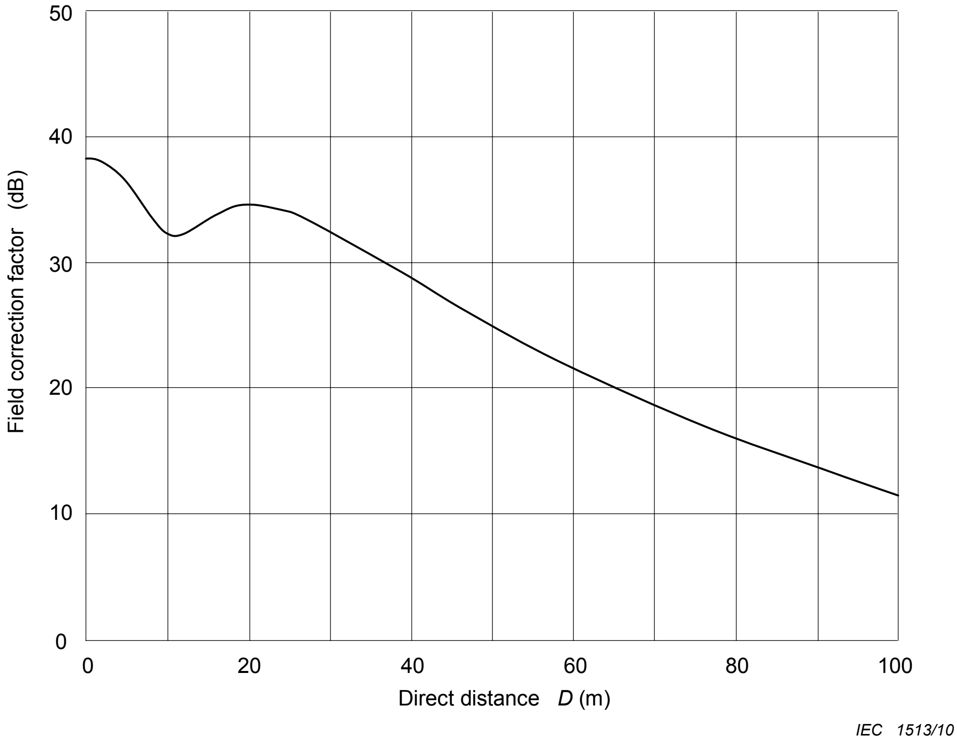


Figure 2 – Line with conductors in a flat configuration

Correction to be applied to the excitation function calculated for the central phase to obtain the radio noise field strength in dB(μV/m) as a function of the direct distance D from the axis of a line having the following characteristics and consequent modal matrix and attenuation factors:

h = 20 m (minimum height above the ground)
S = 15 m (distance between phases)
d = 3 cm (sub-conductor diameter)
n = 8 (number of sub-conductors in a bundle)
s = 450 mm (bundle spacing)
ρ = 100·Ω m (ground resistivity)
f = 0,5 MHz (frequency)

$$\left| N \right| = \begin{vmatrix} 0{,}442 & 0{,}707 & 0{,}552 \\ -0{,}781 & 0{,}0 & 0{,}625 \\ 0{,}442 & -0{,}707 & 0{,}552 \end{vmatrix} \quad \text{(modal matrix)}$$

$\alpha_1 = 10 \times 10^{-6}$ Np/m
$\alpha_2 = 70 \times 10^{-6}$ Np/m (modal attenuation factors)
$\alpha_3 = 350 \times 10^{-6}$ Np/m

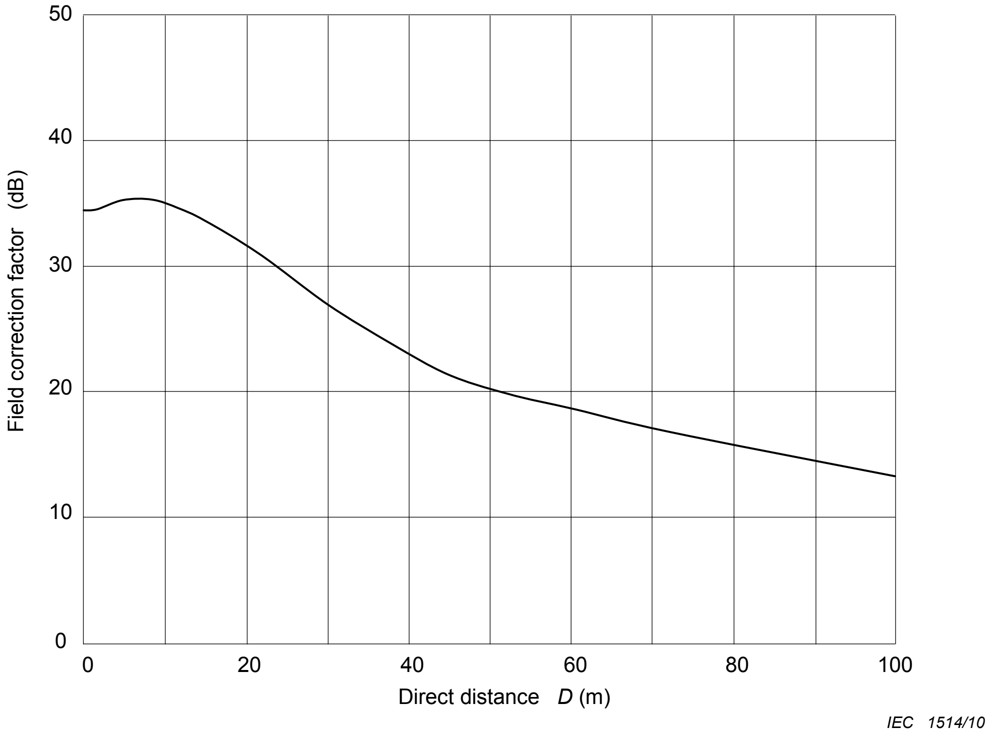


Figure 3 – Line with conductors in a delta configuration

Correction to be applied to the excitation function calculated for the central phase to obtain the radio noise field strength in dB(μV/m) as a function of the direct distance *D* from the axis of a line having the following characteristics and consequent modal matrix and attenuation factors:

h = 20 m (minimum height above the ground of the lateral phases)

h = 33 m (minimum height above the ground of the central phase)

S = 15 m (distance between phases)

d = 3 cm (sub-conductor diameter)

n = 8 (number of sub-conductors in a bundle)

s = 450 mm (bundle spacing)

ρ = 100 Ω·m (ground resistivity)

f = 0,5 MHz (frequency)

$$\left| N \right| = \begin{vmatrix} 0{,}412 & 0{,}707 & 0{,}574 \\ -0{,}812 & 0{,}0 & 0{,}583 \\ 0{,}412 & -0{,}707 & 0{,}574 \end{vmatrix} \quad \text{(modal matrix)}$$

$$\alpha_1 = 10 \times 10^{-6}\ \text{Np/m}$$

$$\alpha_2 = 25 \times 10^{-6}\ \text{Np/m} \quad \text{(modal attenuation factors)}$$

$$\alpha_3 = 300 \times 10^{-6}\ \text{Np/m}$$

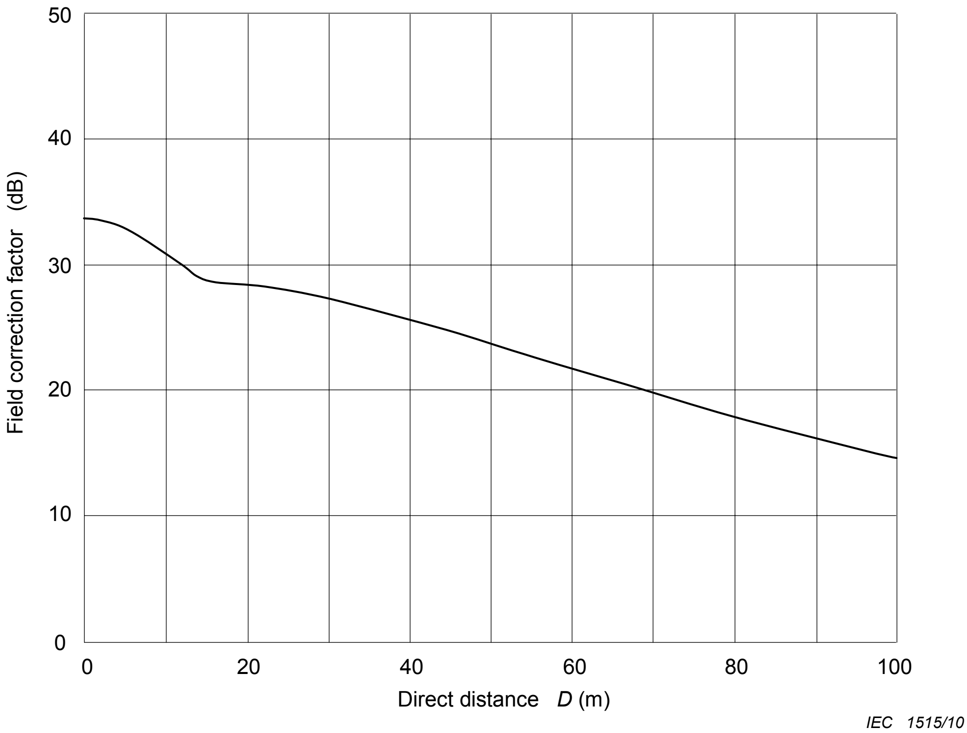


Figure 4 – Line with conductors in a triangular configuration

Correction to be applied to the excitation function calculated for the central phase to obtain the radio noise field strength in dB(μV/m) as a function of the direct distance *D* from the axis of a line having the following characteristics and consequent modal matrix and attenuation factors:

h = 33 m (minimum height above the ground of the lateral phases)

h = 20 m (minimum height above the ground of the central phase)

S = 15 m (distance between phases)

d = 3 cm (sub-conductor diameter)

n = 8 (number of sub-conductors in a bundle)

s = 450 mm (bundle spacing)

ρ = 100 Ω·m (ground resistivity)

f = 0,5 MHz (frequency)

$$\left| N \right| = \left| \begin{matrix} 0{,}476 & 0{,}707 & 0{,}447 \\ -0{,}740 & 0{,}0 & 0{,}775 \\ 0{,}476 & -0{,}707 & 0{,}447 \end{matrix} \right| \quad \text{(modal matrix)}$$

$$\alpha_1 = 25 \times 10^{-6} \text{ Np/m}$$

$$\alpha_2 = 15 \times 10^{-6} \text{ Np/m} \quad \text{(modal attenuation factors)}$$

$$\alpha_3 = 250 \times 10^{-6} \text{ Np/m}$$

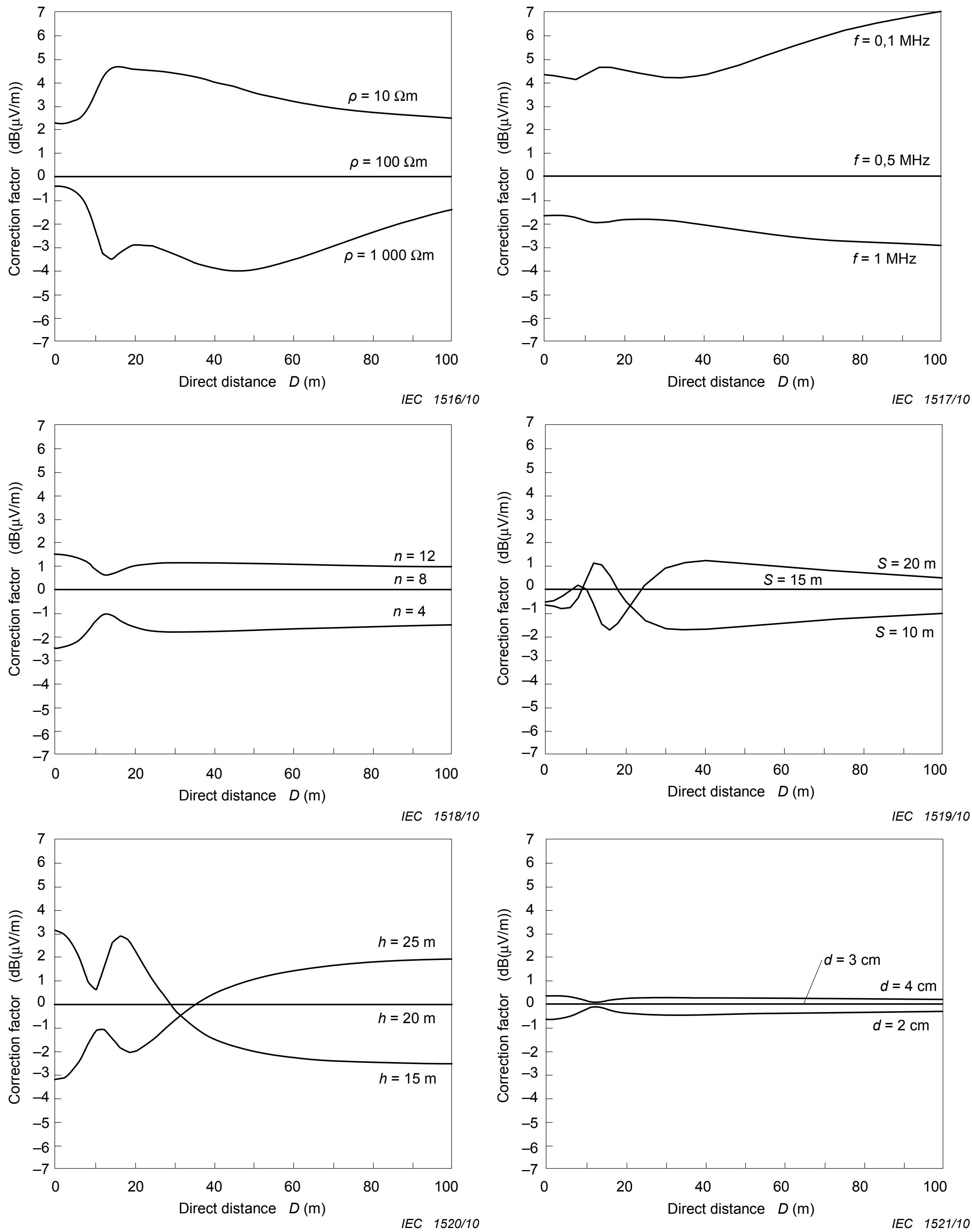


Figure 5 – Line with conductors in a flat configuration

Corrections in dB to be applied to the reference radio noise electric field strength obtained from Figure 2, to account for ground resistivity *ρ*, frequency *f*, number of sub-conductors *n*, interphase spacing *S*, minimum height above the ground *h* and sub-conductor diameter *d*.

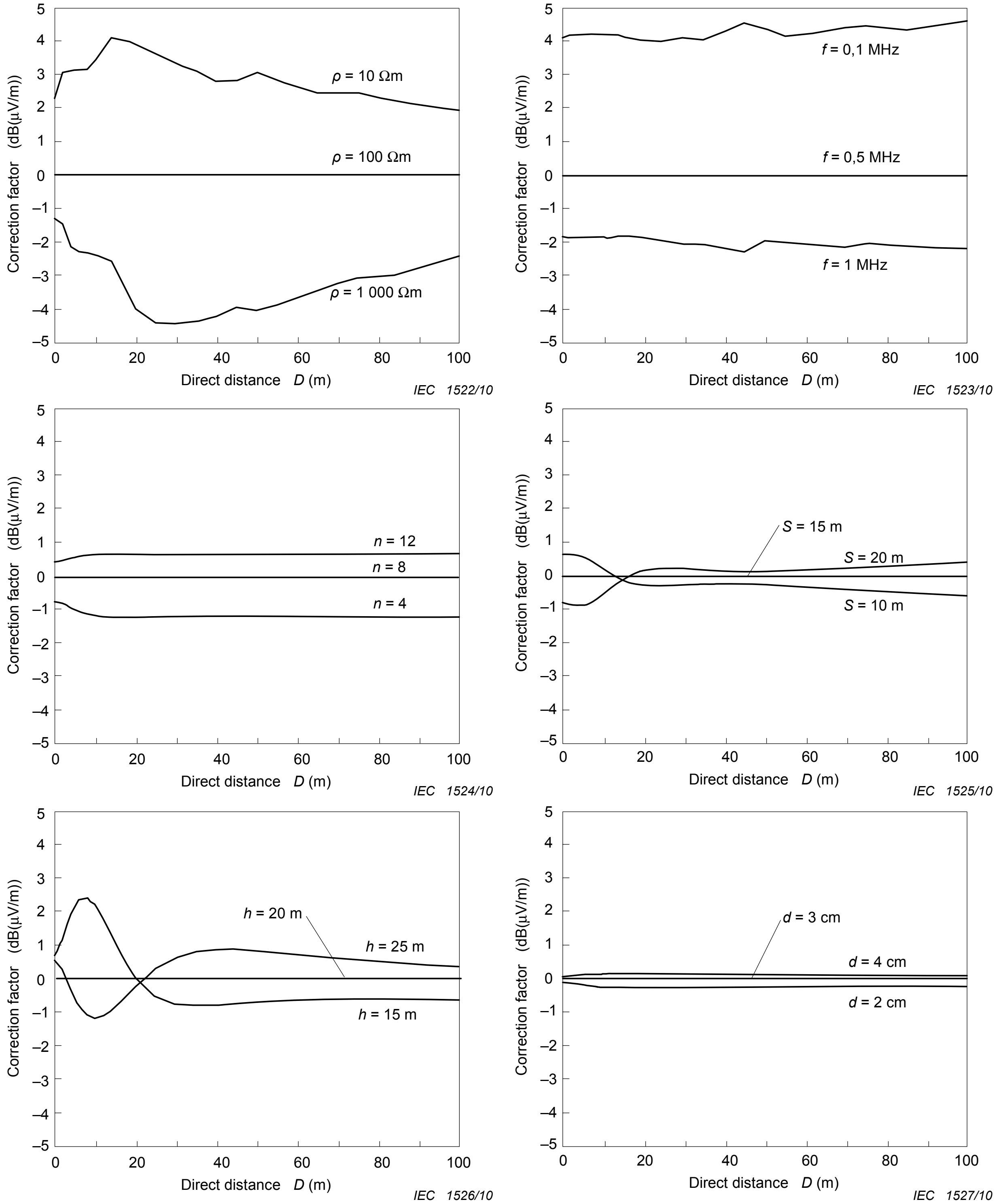


Figure 6 – Line with conductors in a delta configuration

Corrections in dB to be applied to the reference radio noise electric field strength obtained from Figure 3, to account for ground resistivity *ρ*, frequency *f*, number of sub-conductors *n*, interphase spacing *S*, minimum height above the ground *h* and sub-conductor diameter *d*.

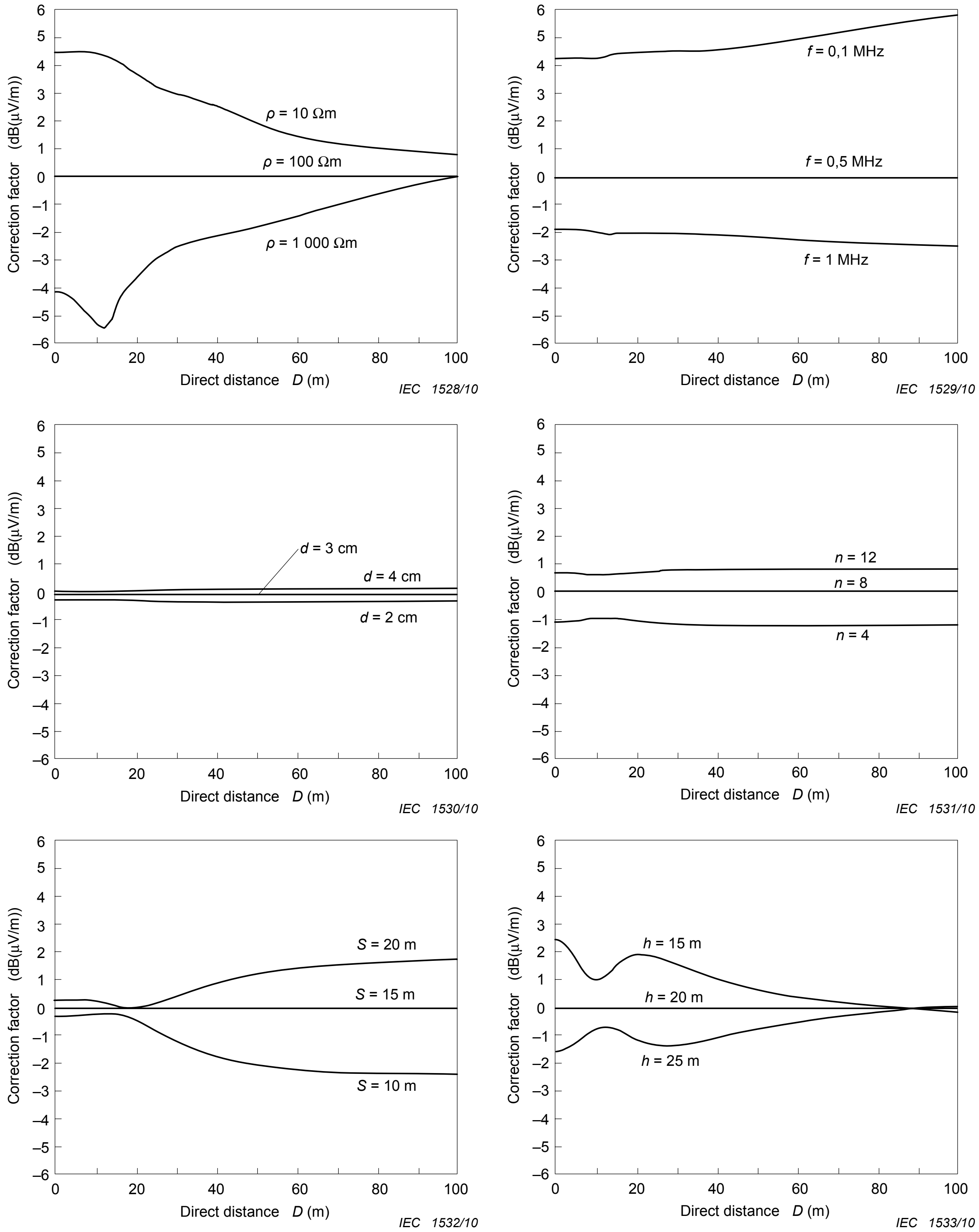


Figure 7 – Line with conductors in a triangular configuration

Corrections in dB to be applied to the reference radio noise electric field strength obtained from Figure 4, to account for ground resistivity *ρ*, frequency *f*, number of sub-conductors *n*, interphase spacing *S*, minimum height above the ground *h* and sub-conductor diameter *d*.

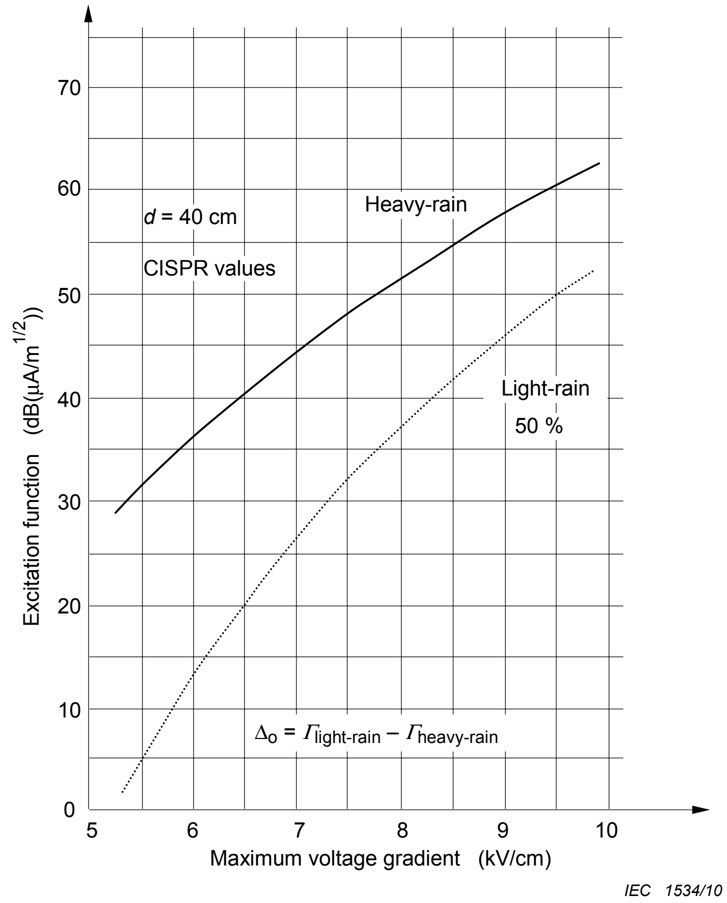


Figure 8 – Tubular conductors of 40 cm diameter

Correction factor in dB to be applied to the heavy rain excitation function to obtain that under light rain as a function of the maximum voltage gradient.

Annex A
(informative)

Formulae for predicting the radio noise field strength from the conductors of an overhead line

A.1 CIGRÉ formula for general use

This simple formula will give the most probable radio noise field strength level and the summation of fields made by a CISPR measuring receiver at a frequency of 500 kHz and at a direct distance of 20 m from the nearest conductor with the antenna 2 m above ground.

The elementary formula for a single phase line is:

$$E = 3{,}5\ g_{\max} + 12\ r - 30, \quad \text{in dB}(\mu\text{V/m}) \tag{A.1}$$

where

E is the level of the radio noise field strength, in dB(μV/m);

g_{max} is the maximum gradient of the r.m.s. value of the voltage at the conductor surface, in kV/cm;

r is the conductor radius, in cm.

Precise calculation of the maximum voltage gradient at the conductor surface is recommended because of its important effect on the radio noise level. A calculation method is suggested in Annex A of CISPR/TR 18-1.

For single-circuit three-phase lines the previous formula can be expanded to:

$$E_1 = 3{,}5\ g_{\max 1} + 12\ r_1 - 33\ \log_{10} \frac{D_1}{20} - 30$$

$$E_2 = 3{,}5\ g_{\max 2} + 12\ r_2 - 33\ \log_{10} \frac{D_2}{20} - 30$$

$$E_3 = 3{,}5\ g_{\max 3} + 12\ r_3 - 33\ \log_{10} \frac{D_3}{20} - 30$$

where D_1, D_2 and D_3 are the direct distances, in metres, from the phase conductors to the antenna of the measuring instrumentation.

These formulae can also be used to determine the level of the radio noise field strength at measuring positions other than the 20 m reference distance.

The summation of these three field strength contributions is made in the following way: if one of the fields is at least 3 dB greater than each of the other two, they are both neglected, otherwise, we have.

$$E = \frac{E_a + E_b}{2} + 1{,}5, \quad \text{in dB}(\mu\text{V/m})$$

where E_a and E_b are the two highest among the above three levels.

For a double circuit line, the radio noise field strength produced by each of the six conductors is calculated as above at the measuring position. The fields produced by the phases corresponding in time are then added quadratically and the three resulting fields are summated as above.

It should be noted that this method will give the most probable noise level of a line in fair weather at 500 kHz. To obtain the level at a frequency different from 500 kHz, the correction shown in Figure B.14 of Annex B of CISPR/TR 18-1 should be used. If calculations have to be made for distance different from 20 m, then the formula in 5.3.6 of CISPR/TR 18-2 should be used.

The radio noise level for weather conditions other than mean dry, fair weather can be estimated using Figure B.14 of Annex B of CISPR/TR 18-1.

The effect of different altitudes of phase conductors above ground can be taken into account by using the following expression:

$$E_h = E_o + \frac{a - a_o}{300}, \quad \text{in dB}(\mu\text{V/m})$$

where E_o is the radio noise field strength level, in dB(μV/m) at an altitude a_o of the respective phase conductor E_o actually belongs to, in m, and E_h is the radio noise field strength, in dB(μV/m), at the observation point of E_o, caused by a phase conductor located at a different altitude a above ground, in m.

A.2 Collation of predetermination formulae used by several institutions around the world

Table A.1 contains an overview about the separate terms of in predetermination formulae used by several institutions around the world. The information in Table A.1 was obtained from a literature research, for more information see [5], [14, 15].

Table A.2 presents the complete formulae comprising all relevant terms as in Table A.1 used for comparison purposes, i.e. for comparison of the radio noise level radiated from different designs of HV overhead power transmission lines.

Table A.3 eventually presents examples for calculations of absolute field strength levels together with the results of these calculations.

Table A.1 – Empirical methods, terms of the predetermination formulae developed by several institutions, survey

Formula	Reference value [dB(µV/m)]	Maximum gradient G [kV/cm]	Conductor diameter	Number of subconductor	Direct Distance D [m]	Frequency f [MHz]	Weather
E	E_0	E_G	E_d	E_n	E_D	E_f	E_{wl}
CIGRE [a]	- 30	3,5 G_m	6 d	–	$-30 \log\left(\frac{D_d}{20}\right)$	–	–
400 kV -FG [b] (Germany)	53,7 ±5	$K_g(G_m - 16,95)$ K_g = 3 for 750 kV class K_g = 3 for other lines, Gradient limits: 15-19 kV/cm	$40 \log\left(\frac{d}{3,93}\right)$	$E_n = -4$, 1 circuit $E_n = 10 \log\left(\frac{n}{4}\right)$, $n > 1$	$20 K_D \log\left(\frac{20}{D}\right)$ $K_D = 1,6 \pm 0,1$ (0,5 to 1 MHz)	$20 \log\left(\frac{1+0,5^2}{1+f^2}\right)$	0 for fair weather 17 ± 3 for rain
ENEL [b] (Italy)	47	$3,8(G_a - 15,0)$	$40 \log\left(\frac{d}{5,0}\right)$	$10 \log(n)$	$30 \log\left(\frac{20}{D_d}\right)$	$20 \log\left(\frac{1+0,5^2}{1+f^2}\right) + \frac{q}{300}$ E_f = 0 for 1 MHz	14 (Foul L_{50})
CRIEPI [b] (Japan)	–	$3,7(G_m - 12,2) \pm 3$	$40 \log\left(\frac{d}{2,53}\right)$	–	$20 \log\left(\frac{10h}{D^2}\right)$ h: height difference between conductor and antenna	$-12(\log f)^2 - 17 \log(f)$	Use of bottom surface gradient G_P
WESTING-HOUSE [b] (USA)	46	$3,5(G_m - 17,5)$	$30 \log\left(\frac{d}{3,51}\right)$	–	$20 \log\left(\frac{30,7h}{D_d^2}\right)$	$10(1-f)$	24 (Rainy L_5)
EGU [b] (Czech Republic)	11	$4,5 G_m$	–	–	$-34 \log(D_d)$	$-22 \log(f) - 15 \log^2(f)$	–

Table A.1 *(continued)*

Formula	Reference value [dB(μV/m)]	Maximum gradient G [kV/cm]	Conductor diameter	Number of subconductor	Direct Distance D [m]	Frequency f [MHz]	Weather
Ontario Hydro [b] (Canada)	R	$A\log\left(\frac{G_m}{18{,}8}\right)$	$40\log\left(\frac{d}{2{,}54}\right)$	–	$B\log\left(\frac{30{,}5}{D_d}\right)$	$20\log\left(\frac{C+1}{C+f^2}\right)$	–
	R = 34 dB ±6 (50 % value, fair weather) horizontal lines R = 37 dB ±6 (50 % value, fair weather) vertical lines R = 63 dB (max. foul weather) horizontal lines R = 66 dB (max. foul weather) vertical lines			A = 146 for fair weather A = 120 for foul weather	B = 40 for horizontal lines B = 32 for vertical lines	C = 1 for $f \geq 1$ MHz C = 0,5 for $f < 1$MHz	
KEPCO [c] (Korea)	- 105,81 - 81,98	$117{,}42\log(G_a)$ $119{,}56\log(G_a)$	$40{,}38\log(d)$ $43{,}57\log(d)$	$1{,}54\log(n)$ $3{,}97\log(n)$	$-10{,}22\log(D_d)$ $-19{,}05\log(D_d)$	$-27{,}10\log(f)$ $-25{,}07\log(f)$	Fair Foul
BPA [d] (USA)	46	$120\log\left(\frac{G_a}{17{,}56}\right)$	$40\log\left(\frac{d}{3{,}51}\right)$	–	$\frac{q}{300} - C1 + C2$	$10\left(1-(\log(10f))^2\right)$	17 (Rainy L_{50}) 24 (Rainy L_5)

a CIGRÉ WG36.01, *Interferences produced by corona effect of electric systems – Description of phenomena practical guide for calculation*, 1974 (see also reference [14]).

b IEEE Radio Noise Subcommittee Report, *Comparison of Radio Noise Prediction Methods With CIGRE/IEEE Survey Results*, IEEE Transactions On Power Apparatus And Systems, Vol. Pas-92, No. 3, May/June 1973 (see also reference [5]).

c Muno Ju, Kwangho Yang, Sungho Myung, Kooyong Shin, Dongil Lee, *Development of New Formulas for Predicting Corona Noise from HVAC Transmission Lines*, ICEE 2002, pp. 2147-2150, 2002 (see also reference [15]).

d CIGRÉ WG36.01, *Interferences produced by corona effect of electric systems – Description of phenomena practical guide for calculation*, December 1996 (see also reference [16]).

Table A.2 – Empirical methods, complete predetermination formulae developed by several institutions, survey

No.	Method	Formulae for comparison purposes Relation $E - E_0$, in dB	Three phase number coefficients Limits of validity, as far as available
1	400 kV FG (DE)	$E - E_0\,[\text{dB}] = K_g \cdot \log_{10}\left(\frac{g_m}{g_{m_0}}\right) + 40\log_{10}\left(\frac{d}{d_0}\right) + 10\log_{10}\left(\frac{n}{n_0}\right) + K_D \cdot \log_{10}\left(\frac{D_0}{D}\right) + 20\log_{10}\left(\frac{1+f_0^2}{1+f^2}\right)$	K_g = 3 for U = 765 kV, and K_g = 3,5 for U ≤ 700 kV, valid in the range 15 kV/cm < g_m < 19 kV/cm. K_D = 32 ±2, valid in the range 0,5 MHz < f < 1 MHz. $E_t = E_1$ for $E_t - E_2 < 3\,\text{dB}$, and $E_t = \frac{E_1 + E_2}{2} + 1{,}5\,\text{dB}$ for $E_t - E_2 \geq 3\,\text{dB}$.
2	ENEL (IT)	$E - E_0\,[\text{dB}] = 3{,}8\log_{10}\left(\frac{g_a}{g_{a_0}}\right) + 40\log_{10}\left(\frac{d}{d_0}\right) + 10\log_{10}\left(\frac{n}{n_0}\right) + 30\log_{10}\left(\frac{D_0}{D}\right) + 20\log_{10}\left(\frac{1+f_0^2}{1+f^2}\right) + \frac{q - q_0}{300}$	E_t = E_1, the values of the components of E_1 from conductors of the same phase to be added quadratically
3	Shiobara (JP)	$E - E_0\,[\text{dB}] = F(g_m) - F(g_0) + 40\log_{10}\left(\frac{d}{d_0}\right) + 20\log_{10}\left(\frac{10\,h}{D^2}\right) - 17\log_{10}\left(\frac{f}{f_0}\right) - 12\left(\log_{10}\left(\frac{f}{f_0}\right)\right)^2$ As g_m, use of bottom-surface gradient G_P.	Fair weather (50 % values): $F(g_m) - F(g_0) = (3{,}7\,g_m - 12{,}2) \pm 3$. Foul weather (in heavy rain): $F(g_m) - F(g_0) = 10{,}5\,g_m - \left(\frac{g_m}{2}\right)^2 - 31$, $g_m \leq 17\,\text{kV/cm}$. $F(g_m) - F(g_0) = 4{,}375\,g_m - \left(\frac{g_m}{4}\right)^2 + 19{,}5\,g_m > 17\,\text{kV/cm}$
4	WESTING-HOUSE (USA)	$E - E_0\,[\text{dB}] = 3{,}5\log_{10}\left(\frac{g_m}{g_{m_0}}\right) + 30\log_{10}\left(\frac{d}{d_0}\right) + 20\log_{10}\left(\frac{h}{h_0}\cdot\left(\frac{D_0}{D}\right)^x\right) + 10\log_{10}\left(\frac{f_0}{f}\right) + 40\log_{10}\left(1 - \frac{\delta}{\delta_0}\right)$	x = 2 for D < 60 m, and x = 1 for D > 60 m, valid in the range 0,2 MHz < f < 1,6 MHz .
5	EGU (CZ)	$E - E_0\,[\text{dB}] = 4{,}5\log_{10}\left(\frac{g_m}{g_{m_0}}\right) + 34\log_{10}\left(\frac{D_0}{D}\right) + 22\log_{10}\left(\frac{f_0}{f}\right) + 15\log_{10}\left(\frac{f_0}{f}\right)^2$	……
6	ONTARIO HYDRE (CA)	$E - E_0\,[\text{dB}] = K_g \cdot \log_{10}\left(\frac{g_m}{g_{m_0}}\right) + 40\log_{10}\left(\frac{d}{d_0}\right) + K_D \cdot \log_{10}\left(\frac{D_0}{D}\right) + 20\log_{10}\left(\frac{c+f_0^2}{c+f^2}\right)$	……

Table A.2 *(continued)*

No.	Method	Formulae for comparison purposes Relation $E - E_0$, in dB	Three phase number coefficients Limits of validity
7	AEP test line method (USA)	$E - E_0\ [\text{dB}] = 3{,}5 \log_{10}\left(\frac{g_m}{g_{m_0}}\right)$	Only for 500 kV and 750 kV lines with the same configuration as the test lines, f_n = 1 MHz . Test line: Configuration A: 500 kV … Configuration B: 750 kV … Configuration C: 750 kV …
8	GE Project EHV, Base Case (USA)	This method gives the average RF disturbance level in fair weather. A series of graphs allow for correction for several parameters, see reference book Edison Electric Institutes - 1968 Chapter V, pp. 173-214 [1].	
9	CIGRE	$E - E_0\ [\text{dB}] = 3{,}5g + 12r - 30$	
10	KEPCO (KR)	Fair weather: $E - E_0\ [\text{dB}] = 117{,}41 \log_{10}\left(\frac{g_a}{g_{a_0}}\right) + 40{,}38 \log_{10}\left(\frac{d}{d_0}\right) + 1{,}54 \log_{10}\left(\frac{n}{n_0}\right) - 10{,}22 \log_{10}\left(\frac{D}{D_0}\right) - 27{,}10 \log_{10}\left(\frac{f}{f_0}\right)$ Foul weather: $E - E_0\ [\text{dB}] = 119{,}56 \log_{10}\left(\frac{g_a}{g_{a_0}}\right) + 43{,}57 \log_{10}\left(\frac{d}{d_0}\right) + 3{,}97 \log_{10}\left(\frac{n}{n_0}\right) - 19{,}05 \log_{10}\left(\frac{D}{D_0}\right) - 25{,}07 \log_{10}\left(\frac{f}{f_0}\right)$	…..
11	BPA (USA)	$E - E_0\ [\text{dB}] = 120 \log_{10}\left(\frac{g_a}{g_{a_0}}\right) + 40 \log_{10}\left(\frac{d}{d_0}\right) + 20 \log_{10}\left(\frac{1+f_0^2}{1+f^2}\right) + \frac{q - q_0}{300} - C_1 + C_2$	

Table A.3 – Predetermination formulae, examples for calculation of the absolute field strength levels

No.	Method	Calculation of the absolute field strength level *E* in dB(µV/m)		Collation of absolute field strength levels [dB(µV/m)] Fair weather	Average foul weather	Average heavy rain
1	400 kV FG (DE)	$E\,[\mathrm{dB}(\mu V/m)] = E_0 + K_g \cdot \log_{10}\left(\frac{g_m}{16{,}95}\right) + 40\log_{10}\left(\frac{d}{3{,}93}\right) + 10\log_{10}\left(\frac{n}{4}\right) + K_D \cdot \log_{10}\left(\frac{20}{D}\right) + 20\log_{10}\left(\frac{1+0{,}5^2}{1+f^2}\right),\ f_0 = 0{,}5\ \mathrm{MHz}$		56 ±5	–	73,7 ±3
2	ENEL (IT)	$E\,[\mathrm{dB}(\mu V/m)] = E_0 + 3{,}8\log_{10}\left(\frac{g_a}{15}\right) + 40\log_{10}\left(\frac{d}{5{,}0}\right) + 10\log_{10}\left(\frac{n}{1}\right) + 30\log_{10}\left(\frac{20}{D}\right) + 20\log_{10}\left(\frac{2}{1+f^2}\right),\ f_0 = 1\ \mathrm{MHz}$		55	64	68
3	Shiobara (JP)	$E\,[\mathrm{dB}(\mu V/m)] = E_0 + F(g_m) - F(g_0) + 40\log_{10}\left(\frac{d}{2{,}33}\right) + 20\log_{10}\left(\frac{10h}{D^2}\right) - 17\log_{10}\left(\frac{1}{f_0}\right) - 12\left(\log_{10}\left(\frac{1}{f_0}\right)\right)^2,\ f_0 = 1\ \mathrm{MHz}$		–	–	–
4	WESTING-HOUSE (USA)	$E\,[\mathrm{dB}(\mu V/m)] = 3{,}5\log_{10}\left(\frac{g_m}{17{,}5}\right) + 30\log_{10}\left(\frac{d}{3{,}51}\right) + 20\log_{10}\left(\frac{h}{13}\cdot\left(\frac{20}{D}\right)^x\right) + 10\log_{10}\left(\frac{1}{f}\right) + 40\log_{10}\left(1-\frac{\delta}{1}\right),\ f_0 = 1\ \mathrm{MHz}$		48	–	70
5	EGU (CZ)	$E\,[\mathrm{dB}(\mu V/m)] = 4{,}5\log_{10}\left(\frac{g_m}{15}\right) + 34\log_{10}\left(\frac{20}{D}\right) + 22\log_{10}\left(\frac{1}{f}\right) + 15\log_{10}\left(\frac{1}{f}\right)^2,\ f_0 = 1\ \mathrm{MHz}$		37	47	–
6	ONTARIO HYDRE (CA)	$E\,[\mathrm{dB}(\mu V/m)] = K_g \cdot \log_{10}\left(\frac{g_m}{18.8}\right) + 40\log_{10}\left(\frac{d}{2{,}54}\right) + K_D \cdot \log_{10}\left(\frac{30{,}5}{D}\right) + 20\log_{10}\left(\frac{c+1}{c+f^2}\right),\ f_0 = 1\ \mathrm{MHz}$		32 (horizontal lines) 36 (vertical lines)	–	61 (worst foul weather, horizontal lines) 36 (worst foul weather, vertical lines)
7	AEP test line method (USA)	$E\,[\mathrm{dB}(\mu V/m)] = 3{,}5\log_{10}\left(\frac{g_m}{g_{m_0}}\right)$	Configuration A	38,7	55,7	62,7
			Configuration B	45,5	62,5	69,5
			Configuration C	50,5	67,5	74,5

Table A.3 *(continued)*

No.	Method	Formulae for calculation of the absolute field strength level *E* in dB(μV/m)	Reference field strength value E_0 [dB(μV/m)]		
			Fair weather	**Average foul weather**	**Average heavy rain**
8	GE Project EHV, Base Case (USA)	This method gives the average RF disturbance level in fair weather. A series of graphs allow for correction for several parameters, see Reference book Edison Electric Institutes - 1968 Chapter V, pp. 173-214 [1].	–	–	–
9	CIGRE	$E\,[\mathrm{dB}(\mu\mathrm{V/m})] = 3{,}5g + 12r - 30,\ f_0 = 1\,\mathrm{MHz}$	-30	–	–
10	KEPCO (KR)	$E\,[\mathrm{dB}(\mu\mathrm{V/m})] = 117{,}41\log_{10}\left(\frac{g_a}{1}\right) + 40{,}38\log_{10}\left(\frac{d}{1}\right) + 1{,}54\log_{10}\left(\frac{n}{1}\right) - 10{,}22\log_{10}\left(\frac{D}{1}\right) - 27{,}10\log_{10}\left(\frac{f}{1}\right),\ f_0 = 1\,\mathrm{MHz}$ $E\,[\mathrm{dB}(\mu\mathrm{V/m})] = 119{,}56\log_{10}\left(\frac{g_a}{1}\right) + 43{,}57\log_{10}\left(\frac{d}{1}\right) + 3{,}97\log_{10}\left(\frac{n}{1}\right) - 19{,}05\log_{10}\left(\frac{D}{1}\right) - 25{,}07\log_{10}\left(\frac{f}{1}\right),\ f_0 = 1\,\mathrm{MHz}$	-105,8	-81,98	–
11	BPA (USA)	$E\,[\mathrm{dB}(\mu\mathrm{V/m})] = 120\log_{10}\left(\frac{g_a}{17{,}56}\right) + 40\log_{10}\left(\frac{d}{3{,}51}\right) + 10\left((1-\log_{10}10f)^2\right) + \frac{q}{300} - C_1 + C_2$	46	63	70

Annex B
(informative)

Analytical procedure for the predetermination of the radio noise field strength, at a given distance from an overhead line with large bundle conductors

B.1 Analytical procedure

The procedure makes reference to the geometry of the line as indicated in Figure B.1.

1) Determination of the corona currents $|i_o|$ at a longitudinal distance x from the reference section, due to the excitation function Γ_1 of phase 1, considered constant along all the line (uniform distribution of corona sources).

$$|i_o| = |C| \cdot |\Gamma| / 2\pi\varepsilon_o \qquad |\Gamma| = \begin{vmatrix} \Gamma_1 \\ 0 \\ 0 \end{vmatrix}$$

where

$|C|$ is the matrix of the line capacitances;

ε_o is the absolute permittivity of air.

2) Determination of the modal currents $|i_{om}|$, by using the modal transformation matrix $|N|$, obtained as the eigenvectors of the matrix $|B| = |Y| \cdot |Z|$ or, in a more simplified analysis, as the eigenvectors of matrix $|C|^{-1}$ ($|Z|$ and $|Y|$ are the series impedance and the shunt admittance matrices, respectively). Typical values of $|N|$ are given for different line configurations in Figures 2, 3 and 4.

$$|i_{om}| = |N|^{-1} \cdot |i_o|$$

Determination of the modal currents $|i_m(x)|$ at the reference section of the line, by using the modal propagation factors ($\lambda_m = \alpha_m + j \cdot \beta_m$) and considering subdivision of the currents into the two sections of the line.

$$|i_m(x)| = 0{,}5 \exp(-\lambda_m \cdot x) \cdot |i_{om}| \qquad (m = 1 \text{ à } 3)$$

The factors λ_m are obtained as eigenvalues of the matrix $|B|$ or experimentally. Typical values of α_m are given for different line configurations in Figures 2, 3 and 4.

3) Determination of the phase currents at the reference section of the line.

$$|i(x)| = |N| \cdot |i_m(x)|$$

4) Determination of the horizontal component of the magnetic field strength $H_1(x,y)$ and the corresponding vertical component of the electric field strength $E_1(x,y)$ at a given lateral distance y from a reference position.

$$E_1(x,y) = 120\,\pi \cdot H_1(x,y) = 60\,\Sigma_j\, i_j(x) \cdot F_j(y)$$

where

$$F_j(y) = z_j/[z^2 + (y - y_j)^2] + (z_j + 2p) / [(z_j + 2p)^2 + (y - y_j)^2]$$

and

$p = \sqrt{(\rho / \pi\mu_o f)}$;

ρ is the ground resistivity (Ω·m);

f is the frequency (Hz);

μ_o is the magnetic permittivity of the free space.

5) Accumulation according to a quadratic law, of the field strength contributions due to all the corona sources at various longitudinal distances from the reference line section.

$$E_1(y) = \sqrt{\left(2 \int \left| E_1(x,y) \right|^2 dx\right)}$$

Introducing the previous expression for $E_1(x,y)$, performing the integration and assuming $\beta_m - \beta_n = \alpha_m - \alpha_n$, the following expression for $E_1(x)$ may be obtained:

$$E_1(y) = \sqrt{\left\{\Sigma_m \left(A_m^2 / \alpha_m\right) + \Sigma_{m,n}^2 \left[A_m \cdot A_n \cdot (\alpha_m + \alpha_n) / (\alpha_m^2 + \alpha_n^2)\right]\right\}}$$

$A_m = 30\ i_{om}\ \ \Sigma_i\ [N_{i,m}\ \ F_i(y)]$ (m,n = modes; i = phases)

6) With reference to the same lateral distance *y*, the same calculation method is applied assuming corona generation on phases 2 and 3.

$$|\Gamma|_2 = \begin{vmatrix} 0 \\ \Gamma_2 \\ 0 \end{vmatrix} \qquad |\Gamma|_3 = \begin{vmatrix} 0 \\ 0 \\ \Gamma_3 \end{vmatrix}$$

7) Putting the three values of electric field strengths, expressed in dB(µV/m), in decreasing order [$E_a(y)$ E_b(y) E_c(y)], the level of the total field strength $E(y)$ in dB(µV/m) is obtained, according to the CISPR rule, as follows:

$E(y) = E_a(y)$, if $E_a(y)$ $E_b(y)$ + 3 dB,

$E(y) = [E_a(y) + E_b(y)]/2$ + 1,5 dB in the other cases.

NOTE For double circuit lines, the same procedure is applied, calculating the absolute field strength values $E_1'(y)$, $E_1''(y)$; $E_2'(y)$, $E_2''(y)$; $E_3'(y)$, $E_3''(y)$.

$$E_1(y) = \sqrt{\left[E_1'(y) + E_1''(y)\right]}$$

$$E_2(y) = \sqrt{\left[E_2'(y) + E_2''(y)\right]}$$

$$E_3(y) = \sqrt{\left[E_3'(y) + E_3''(y)\right]}$$

An example of the procedure illustrated above is given in Clause B.2.

B.2 Example of calculation of the radio noise field strength

Given a line with the following characteristics (reference is made to the scheme of Figure 2).

Voltage	V = 1 050 kV
Number of sub-conductors	n = 8
Subconductor diameter	d = 3 cm
Spacing between sub-conductors	s = 45 cm
Minimum height on the ground	$h_1 = h_2 = h_3$ = 20 m
Sag	15 m
Interphase spacing	S = 15 m
Two earth wires	
Earth resistivity	ρ = 100 Ω·m

Then the maximum voltage gradients are (see CISPR/TR 18-1, Annex A):

for the lateral phases	16,5 kV/cm
for the central phase	18,2 kV/cm

The excitation functions in heavy rain (see 7.2.2):

for the lateral phases 70 – 35,45 + 16,7 – 9,03 = 42,2 dB(μA/m$^{1/2}$)
(corresponding to 128 μA/$\sqrt{\text{m}}$)

for the central phase 70 – 32,18 + 16,7 – 9,03 = 45,5 dB(μA/m$^{1/2}$)
(corresponding to 188 μA/$\sqrt{\text{m}}$)

The matrix of capacitances:

$$\left| C \right| / 2\pi\varepsilon_0 = \begin{vmatrix} 0{,}244\,2 & -0{,}049\,1 & -0{,}012\,3 \\ -0{,}049\,1 & 0{,}256\,3 & -0{,}049\,1 \\ -0{,}012\,3 & -0{,}049\,1 & 0{,}244\,2 \end{vmatrix}$$

Consider first corona generation on phase 1 only. Then:

$$\left| \Gamma \right|_1 = \begin{vmatrix} 128 \\ 0{,}0 \\ 0{,}0 \end{vmatrix} \qquad (\mu\text{A}/\sqrt{\text{m}})$$

$$\left| i_0 \right| = \left| C \right| \cdot \left| \Gamma \right|_1 / 2\pi\varepsilon_0 = \begin{vmatrix} 0{,}244\,2\times128 \\ -0{,}049\,1\times128 \\ -0{,}012\,3\times128 \end{vmatrix} = \begin{vmatrix} 31{,}25 \\ -6{,}28 \\ -1{,}57 \end{vmatrix} \qquad (\mu\text{A}/\sqrt{\text{m}})$$

Assuming, for the simplified analysis:

$$\left| N \right| = \begin{vmatrix} 0{,}442 & 0{,}707 & 0{,}552 \\ -0{,}781 & 0{,}0 & 0{,}625 \\ 0{,}421 & -0{,}707 & 0{,}552 \end{vmatrix} \qquad [\left| N \right|^{-1} = \left| N \right|^{\mathrm{T}}]$$

The modal currents at the generation section of the line then result in:

$$|i_o(m)| = |N|^{-1} \cdot |i_o| = \begin{vmatrix} 18,02 \\ 23,22 \\ 12,47 \end{vmatrix} \qquad (\mu A/\sqrt{m})$$

Assuming the penetration depth p = 7,1 m, the field factors then result in:

y (in metres)	$F_1(y)$	$F_2(y)$	$F_3(y)$
0	0,055 25	0,10	0,055 25
10	0,033 78	0,08	0,096 15
20	0,021 69	0,05	0,099 01
30	0,014 79	0,030 76	0,058 14
40	0,010 63	0,02	0,045 25
50	0,007 96	0,013 79	0,028 09

The modal attenuation factors for the line under consideration (with ρ = 100 Ω·m and f = 0,5 MHz) are assumed to be

α_1 = 10 × 10^{-6} Np/m

α_2 = 70 × 10^{-6} Np/m

α_3 = 350 × 10^{-6} Np/m

The electric field strength level $E_1(y)$ results in:

Y (in metres)	$E_1(y)$ (in dB(μV/m))
0	71,0
10	70,2
20	69,2
30	66,3
40	62,7
50	59,4

Consideration of corona generation on phase 2 only.

$$|\Gamma|_2 = \begin{vmatrix} 0,0 \\ 188 \\ 0,0 \end{vmatrix} \qquad (\mu A/\sqrt{m})$$

With the same approach as before, the electric field strength level $E_2(y)$ results in:

y (in metres)	$E_2(y)$ (in dB(μV/m))
0	79,9
10	77,9
20	76,0
30	73,1
40	69,7
50	66,5

Consideration of corona generation on phase 3 only.

$$\left| \Gamma \right|_3 = \begin{vmatrix} 0{,}0 \\ 0{,}0 \\ 128 \end{vmatrix} \qquad (\mu A/\sqrt{m})$$

With the same approach as before, the electric field strength level $E_3(y)$ results:

y (in metres)	$E_3(y)$ (in dB(μV/m))
0	71,0
10	74,1
20	75,1
30	72,3
40	68,5
50	63,1

Total electric field evaluation

According to the CISPR rule, the total electric field strength level is then:

y (in metres)	$E(y)$ (in dB(μV/m))
0	79,9
10	77,9
20	77,1
30	74,2
40	70,6
50	67,1

The lateral field strength profiles of E_1, E_2, E_3 and of the total field strength E are plotted in Figure B.2.

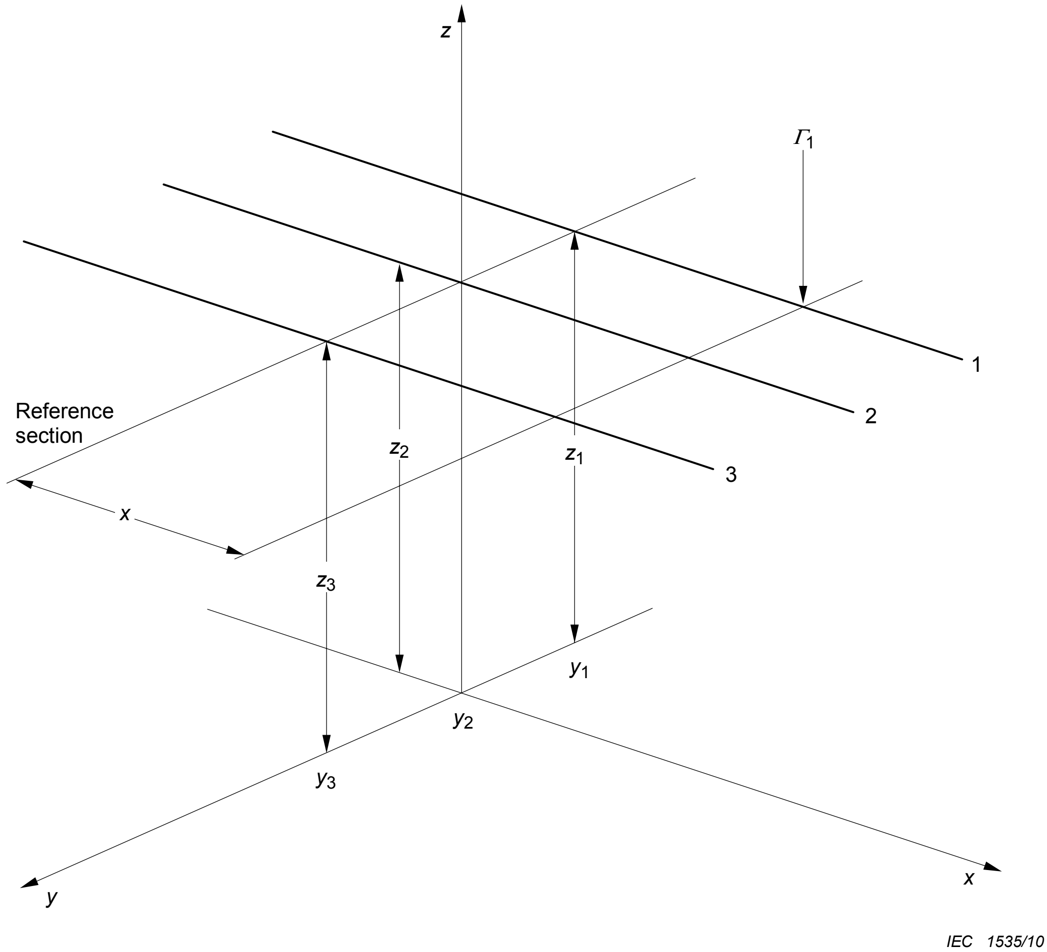
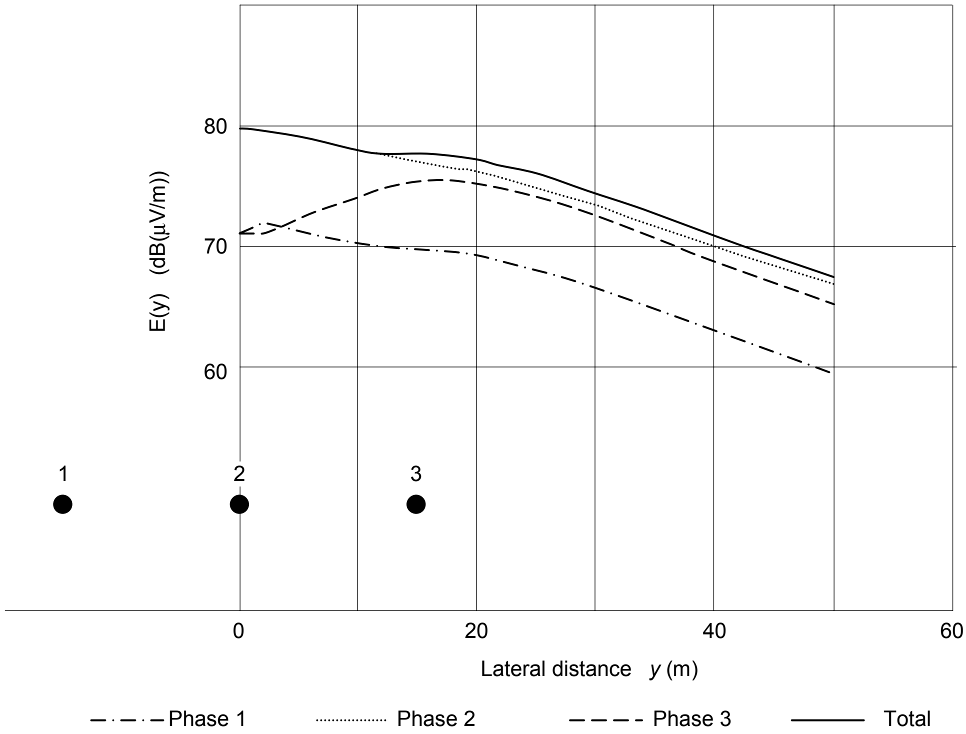


Figure B.1 – Designation of the geometrical quantities for the simplified analytical method



IEC 1536/10

Figure B.2 – Lateral profiles of the radio noise field strengths produced by the individual phases and of the total field, as calculated in the given example

Bibliography

[1] Project EHV; General Electric Company, *EHV transmission line reference book*, Edison Electric Institute NY 1968, Chapter V, pp. 173-214.

[2] Y. Sawada: *Calculating Method of Radio Noise Level and Its Application to Design of AC power Transmission Line*, IEEE Transactions on Power Apparatus and Systems, vol. 89, pp. 844-853, May/June 1970.

[3] Y. Sawada, T. Sugimoto, M. Ushirozawa*: Radio Noise and Corona Loss of 500 kV Power Transmission Line and Substation*, CRIEPI Report No. 7 (Japanese), Central Research Institute of Electric Power Industry (CRIEPI), Japan, June 1970.

[4] J.J. Clade, C.H. Gary, M.R. Moreau: *Usage and Checking of the Theoretical Relations Between Fields, Currents, and Excitation Functions in Radio Frequencies in the Case of Short Test Lines*, IEEE Transactions on Power Apparatus and Systems, vol. 88, pp. 1501-1511, October 1969.

[5] CIGRÉ-IEEE Committee Report: *Comparison of Radio Noise Prediction Methods with CIGRÉ-IEEE Survey Results*, IEEE Transactions on PAS, May/June 1973, vol. 92, pp.1029-1042.

[6] Addendum to *"Interferences Produced by Corona Effect of Electric Systems (Description of the phenomena and practical guide for calculation)"*. By CIGRÉ WG on Corona and Field Effects. To be published as CIGRÉ Brochure.

[7] R. G. Olsen, S. D. Schennum, V. L. Chartier: *Comparison of several methods for calculating power line electromagnetic interference levels and calibration with long term data*. IEEE Transactions on Power delivery, Vol. 7, No. 2, April 1992.

[8] R. D. Dallaire, P. Sarma Maruvada: *Analysis of radio interference from short multi-conductor lines. Part 1: Theoretical analysis*. IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 4, April 1981

[9] R. D. Dallaire, P. Sarma Maruvada: *Analysis of radio interference from short multi-conductor lines. Part 1: Analytical and test results*. IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 4, April 1981

[10] B. A. Cauzillo, R. Cortina, P. Nicolini, J. C. De Medeeiros, M. E. Bryant: *Design criteria of UHV lines based on experience acquired in the 1 000 kV Project*. CIGRÉ 22-14, 1984.

[11] Y. Sawada, M. Fukushima, M. Yasui: Akagi 1000 kV Project in CRIEPI. *Corona test facilities and results up to 1983*. CIGRÉ 36-05, 1984.

[12] M. Fukushima, T. Sasano, Y. Sawada: *Corona performance of conductor bundles measured in corona cages and its application*. CIGRÉ Symposium 22-81, No. 232-01, June 1981.

[13] P. Z. Rokhinson, A. S. Sokhransky, L. V. Timashova, N. N. Tykhodeev: *Corona effects of high bundle number UHV conductors: energy losses, radio and TV interference*. CIGRÉ 36-09, 1988.

[14] Table 4.1 in *'Interferences produced by corona effect of electric system: Description of phenomena practical guide for calculation',* by CIGRE WG36.01 in 1974.

[15] Muno Ju, Kwangho Yang, Sungho Myung, Kooyong Shin, Dongil Lee, *“Development of New Formulas for Predicting Corona Noise from HVAC Transmission Lines”*, ICEE 2002 pp. 2147-2150, 2002.

[16] CIGRE WG36.01, *Interferences produced by corona effect of electric systems – Description of phenomena practical guide for calculation*, December 1996.

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch