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Radio interference characteristics of overhead power lines and high-voltage equipment —

Part 2: Methods of measurement and procedure for determining limits

ICS 29.240.20; 33.100

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the General Electrotechnical Standards Policy Committee (GEL/-) to Technical Committee GEL/110, upon which the following bodies were represented:

Association of Control Manufacturers (TACMA) (BEAMA Ltd.)
Association of Manufacturers of Domestic Electrical Appliances
BEAMA Interactive and Mains Systems Association (BIMSA)
BEAMA Ltd.
British Industrial Truck Association
British Lighting Assocation for the Preparation of Standards (Britlaps)
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Society of Motor Manufacturers and Traders Limited
Sound and Communications Industries Federation
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The following bodies were also represented in the drafting of the standard, through sub-committees and panels:

Association of Manufacturers Allied to the Electrical and Electronic Industry (BEAMA Ltd.)
British Industrial Ceramic Manufacturers' Association
Bus and Coach Council
Department of Trade and Industry (Electricity Division)
Electrical and Electronic Insulation Association (BEAMA Ltd.)
Railway Industry Association of Great Britain

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Contents

National foreword

This Part of BS 5049 has been prepared under the direction of the General Electrotechnical Standards Policy Committee. It is identical with CISPR 18-2:1986 *Radio interference characteristics of overhead power lines and high voltage equipment Part 2 Methods of measurement and procedures for determining limits,* including Amendment 1:1993 and Amendment 2:1996, published by the International Electrotechnical Commission (IEC) on behalf of the International Special Committee on Radio Interference.

This Part of BS 5049 supersedes BS 5049:1987 which is withdrawn.

Cross-references

International standard	Corresponding British Standard
IEC 60-2[a]	BS 923 *Guide on high-voltage testing techniques* Part 1:1990 *General* (Identical) BS 5049 *Radio interference characteristics of overhead power lines and high-voltage equipment*
CISPR 18-1:1982	Part 1:1994 *Description of phenomena* (Identical)
CISPR 18-3:1986	Part 3:1994 *Code of practice for minimizing the generation of radio noise* (Identical)

[a] IEC 60-2 is superseded by IEC 60-1:1989 which is identical with BS 923-1:1990.

The Technical Committee has reviewed the provisions of IEC 437 and CIPSR 16, to which normative reference is made in the text, and has decided that they are acceptable for use in conjunction with this standard.

References to page numbers in the text are to page numbers in CISPR 18-2 (1986) and should be ignored for the purposes of this British Standard.

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Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 60, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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Scope and object

This publication 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.

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

The clause on limits concentrates on the low frequency and medium frequency bands as it is only in these that ample evidence, based on established practice, is available. No examples of limits to protect reception in the frequency band 30 MHz to 300 MHz have been given, as measuring methods and certain other aspects of the problems in this band have not yet been fully resolved. Site measurements and service experience have shown that levels of noise from power lines at frequencies higher than 300 MHz are so low that interference is unlikely to be caused to television reception.

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

The measuring apparatus and methods used for checking compliance with limits shall conform to C.I.S.P.R. specifications, for example C.I.S.P.R. Publication 16: C.I.S.P.R. Specification for Radio Interference Measuring Apparatus and Measurement Methods. For the frequency range above 30 MHz, the measuring methods are still under consideration by C.I.S.P.R. although some basic aspects are given in C.I.S.P.R. Publication 16.

1 Measurements

1.1 Measuring instruments

1.1.1 *Response of a standard C.I.S.P.R. measuring set to a.c. generated corona noise*

C.I.S.P.R. Publication 16 specifies the response characteristic of a measuring set to periodically repeated pulses, according to their repetition frequency, for a number of measuring sets of differing frequency range and bandwidth including the range 0.15 MHz to 30 MHz and a bandwidth of 9 kHz.

Figure 1, indicates the form these pulses take as they progress through the various stages of the measuring set. However, in the special case of corona pulses generated by high-voltage a.c. power systems, the individual pulses are not equally spaced throughout a cycle but occur in closely packed groups or bursts around the peaks of the voltage waveform. A burst has a duration not exceeding 2 ms to 3 ms and this is followed by a quiescent no-corona period.

Owing to its inherent time constants, a C.I.S.P.R. measuring set is unable to respond to individual pulses within a burst, which is seen as a single pulse whose amplitude is discussed below.

Hence, the pulse repetition frequency, in the meaning of the C.I.S.P.R. definition, is constant at $2f$ (where f is the power system frequency) for single phase and $6f$ for three-phase single or multi-circuit systems, provided that the individual circuits are part of the same system.

Figure 2, indicates the usual case where individual corona pulses generated around the positive peaks of the voltage waveform are much greater in amplitude than those generated around the negative peaks. Hence in a three-phase power line there are three bursts of higher amplitude and three bursts of lower amplitude noise during each period of $1/f$.

Also, in the measurement of the radio noise field in the close vicinity of an operational line, the measuring set aerial is not located at the same distance from all the phase conductors. Then because a quasi-peak detector responds only to the higher amplitude bursts and disregards the lower ones, rules of summation of the radio noise generated by the individual phases of a line can be formulated which are specific to the C.I.S.P.R. characteristics and are given in Clause **2** of C.I.S.P.R. Publication 18-3: Radio Interference Characteristics of Overhead Power Lines and High-voltage Equipment, Part 3: Code of Practice for Minimizing the Generation of Radio Noise. It should be noted that the loudspeaker of a radio receiver, and consequently the listener, perceives the overall generated noise.

To examine the response of the C.I.S.P.R. measuring set to a given burst of pulses, it should be borne in mind that each individual pulse becomes, at the output of the amplifier of Figure 1 of pass-band Δf, a damped oscillation whose duration can be taken as approximately 2/B, or 0.22 ms for 9 kHz. When there is a large number of pulses distributed at random within a burst, the resulting oscillations will overlap randomly and the overall quasi-peak signal will be approximately equal to the quadratic sum of the individual quasi-peak values. This statement, which is difficult to prove mathematically, has been well proven by experience and justifies the use, in quasi-peak detection, of the quadratic summation law which would moreover be rigorous if the noise levels were expressed in r.m.s. values.

1.1.2 ***Other measuring instruments***

Measuring instruments differing from standard C.I.S.P.R. instruments are referred to in Appendix A although measuring apparatus having detectors other than quasi-peak are referred to in C.I.S.P.R. Publication 16.

1.2 C.I.S.P.R. site measurements — 0.15 MHz to 30 MHz range

1.2.1 ***Measurement frequency***

The reference measurement frequency is 0.5 MHz. It is recommended that measurements are made at a frequency of 0.5 MHz ± 10 % but other frequencies, for example 1 MHz, may be used. The frequency of 0.5 MHz (or 1 MHz) is preferred because, usually, the level of radio noise at this part of the spectrum is representative of the higher levels and also because 0.5 MHz lies between the low and medium frequency broadcast bands.

Because of the possibility of error due to the presence of standing waves, it is inadvisable to rely on the measured value of the radio noise field at a single frequency but to draw a mean curve through the results of a number of readings throughout the noise spectrum. Measurements should be made at, or near, the following frequencies: 0.15, 0.25, 0.5, 1.0, 1.5, 3.0, 6.0, 10, 15 and 30 MHz although, clearly, frequencies at which interference to the wanted noise is received, should be avoided.

1.2.2 ***Aerial***

The aerial shall be an electrically-screened vertical loop, whose dimensions are such that the aerial will be completely enclosed by a square having a side of 60 cm in length. The balance shall be such that in a uniform field the ratio between the maximum and minimum indications on the measuring equipment when the aerial is rotated shall not be less than 20 dB. The base of the loop should be about 2 m above ground. The aerial shall be rotated around a vertical axis and the maximum indication noted. If the plane of the loop is not effectively parallel to the direction of the power line, the orientation should be stated.

The measurements may be carried out using a vertical rod aerial although this method is not preferred because of the higher instability of the electric component of the radio noise field and because of possible electric induction effects from the power-frequency voltage.

A check shall be made to ensure that the supply mains, if used, or other conductors connected to the measuring apparatus do not affect the measurements.

1.2.3 ***Distance of measurement***

It is necessary to determine the lateral profile of the radio noise field. For purposes of comparison, the reference distance defining the noise level of the line shall be 20 m. The distance shall be measured from the centre of the loop to the nearest conductor. The height of the conductor above ground should be noted. If the field is plotted as a function of the distance using a logarithmic scale, a substantially straight line is obtained. Under these conditions, the field at 20 m is readily obtained by interpolation or extrapolation (see Figure 3).

1.2.4 ***Position of measurement***

To determine the radio noise performance of a line certain positions of measurement should be avoided; but these restrictions would not apply when an investigation into a case of interference is being carried out.

Measurements should be made at mid-span and preferably at several such positions. Measurements should not be made near points where lines change direction or intersect.

Sites at an abnormal height of span should be avoided. The measuring site should be flat, free from trees and bushes and be some distance from large metal structures and from other overhead power and telephone lines.

Ideally the measuring site should be at a distance greater than 10 km from a line termination, in order to avoid reflection effects and consequently inaccurate results, but lower voltage distribution lines are sometimes too short to enable this condition to be met. However, the results of measurements (Reference [33][1] of C.I.S.P.R. Publication 18-1: Radio Interference Characteristics of Overhead Power Lines and High-voltage Equipment, Part 1: Description of Phenomena) indicate that the level of the radio noise field in the absence of reflections corresponds to the geometric mean of the maximum and minimum values, in microvolts per metre (μV/m), of the frequency spectrum from a line subjected to reflections.

If the line is transposed, the measuring site should be located as far as possible from the transposition towers.

The atmospheric conditions should be approximately uniform along the line. Measurements under rain conditions will be valid only if the rain extends over at least 10 km of the line on either side of the measuring site.

1.2.5 ***Additional information to be given in the report***

To ensure that extraneous interference is not influencing the measurement of the levels of the line radio noise field it may be necessary to measure the noise levels with the line de-energized.

When the results of the measurements are reported, as much relevant information as possible should be given on the line and on the conditions under which the measurements were carried out.

Appendix B gives a list of such information.

1.3 C.I.S.P.R. laboratory measurements

1.3.1 ***Introduction***

This clause gives the method to be used for the measurement, in a laboratory or test area, of radio noise generated by items of plant and components used on high-voltage lines and in substations, such as circuit-breakers, bushings, insulators and fittings. This method is valid for type tests and for routine or sample tests and also for investigational tests.

It is usual practice to carry out laboratory measurements of radio noise in a prescribed test circuit by measuring conducted quantities (current or voltage) and not the emitted field.

Furthermore, the selection of test conditions should be based on the following principle: ideally, the measurements should be made with the conditions and circuit simulating, as far as possible, actual service conditions and, if necessary, the most severe conditions likely to occur for the type of apparatus tested. Before the establishment of a reliable method of radio noise testing in a laboratory, reliance was placed on the voltage at which inception or extinction of visual corona occurred on the test object. The voltages so determined were very dependent on the observer and this method is now being replaced by the laboratory measurements described below.

1.3.2 ***State of the test object***

It is well known that radio noise levels produced by high-voltage equipment are very dependent on the state of the surface of the item of equipment. In laboratory tests, the state of a particular test object should consequently be clearly defined with regard to the following aspects:

a) new or already used;

b) clean or slightly polluted; the nature of the pollution should be specified;

c) dry, slightly damp, or wet (for example artificial rain conditions);

d) combination of these states, for example polluted and damp.

Generally, standards and normal practice are restricted to laboratory tests on clean and dry objects, reproducibility of the other test conditions (dampness, pollution) being often difficult to achieve. However, tests on objects submitted to (standardized) rain conditions may be very useful, since these conditions occur frequently in practice and may lead to significantly higher radio noise levels than dry conditions.

When only one surface condition is taken into consideration, it is desirable, in order to be as close as possible to the practical conditions, that the tests be performed on adequately polluted and wet samples, at the normal operating voltage.

[1] The figures in square brackets refer to “Bibliography and references” of C.I.S.P.R. Publication 18-1 (pages 69 to 71) and of this part (page 58).

When the object is to be tested in a clean and dry state, it may be wiped with a dry cloth to remove dust and fibres that might affect the surface.

Unless otherwise stated, test conditions described in this clause are valid for used, wet and/or polluted objects as well as for new, clean and dry objects.

1.3.3 ***Test area***

The tests should preferably be performed inside a screened room which is large enough to prevent the walls and the floor from having any significant effect on the distribution of the electric field at the surface of the test object. Circuits, for example power and lighting, entering the screened test area should, ideally, be filtered so as to avoid the introduction of radio noise present in the environment (see Sub-clause **1.3.11**).

If a screened room is not available, the tests may be carried out at any place where the background noise level is sufficiently low compared with the levels to be measured (see Sub-clause **1.3.11**).

1.3.4 ***Atmospheric conditions***

The normal reference atmosphere for tests described herein is:

— temperature: 20 °C;

— pressure: 1.013×10^5 N/m^2 (1 013 mbar);

— relative humidity: 65 %.

However these tests may be performed under the following atmospheric conditions:

— temperature: between 15 °C and 35 °C;

— pressure: between 0.870 × 105 N/m^2 and 1.070×10^5 N/m^2 (870 mbar and 1 070 mbar);

— relative humidity (for tests on objects in the dry state): 45 % to 75 %.

In the case of investigational tests, other conditions may be selected according to the test objective.

When tests are made on a dry object, it shall be in thermal equilibrium with the test area atmosphere to avoid any condensation on the surface of the object.

As far as the radio noise levels generated by a test object are concerned, the effects of changes in atmospheric conditions, within the above limits, from the normal reference conditions are little known. Thus no correction shall be applied to the measured results but the air temperature, air pressure and relative humidity obtaining during the tests shall be recorded.

1.3.5 ***Test circuit — Basic diagram***

Figure 4, shows the principle of the test circuit. The radio-frequency currents generated by the test object flow through that part of the circuit shown by heavy lines which include impedance Z_s and resistance R_L. The radio-frequency rejection filter F virtually prevents these currents from flowing in the high-voltage connections to the transformer and, conversely, any interference currents from other sources present in this high-voltage connection are attenuated by the filter before entering the high frequency part of the circuit. Ideally the impedance of Z_s should be zero at the measurement frequency and infinite at the power supply frequency. Also if R_L represents the resistive load of the test object in service, for example the characteristic impedance of a high voltage line, the radio noise voltage which the test object would inject onto a line conductor or substation connection may be measured across R_L.

C.I.S.P.R. Publication 16 specifies a value of 300 Ω for R_L and in a practical test circuit (see Figure 5), R_L is the equivalent resistance of R_2 in series with the parallel combination of R_1 and the input resistance of the measuring set, R_m.

The test consists of taking measurements, expressed in microvolts (or in decibels relative to 1 µV) of the pulse-type voltages appearing across a fraction of R_L when a given power-frequency voltage is applied to the object under test.

1.3.6 ***Practical arrangement of the test circuit***

Figure 5 shows the standard test circuit which should be used for the laboratory measurement of the radio noise voltages generated by medium and/or high voltage equipment. The connections to the measuring set are shown in a simplified form in Figure 5 and, depending on the distance between the measuring set and the test circuit, the arrangement shown in either Figure 6 or Figure 7, is incorporated into the circuit of Figure 5.

NOTE In the special, limited, case of the need for rapid comparative measurements to be made on a number of identical small objects, such as cap and pin insulator units for overhead lines, the special test circuit of Figure 8; may be used. The decoupling capacitor C_m may be omitted when the number of test objects exceeds five.

The impedance Z_s in the basic circuit of Figure 4, can consist of i) a series circuit L_2 C_2 or ii) simply a capacitor C_3, as shown in Figure 5.

i) L_2C_2 is tuned to the measurement frequency along with L_1 in parallel with C_1, forming the rejection filter F. The advantage of this arrangement is that C_2 may have a relatively low value of capacitance, say 50 pF to 100 pF and therefore be cheaper, but the disadvantage is that measurements at frequencies other than the reference frequency involve the returning of L_2C_2 and L_1C_1.

ii) As stated in Item d) of Sub-clause **1.3.7**, a value of 1 000 pF for C_3 should be satisfactory, which makes an inductor in series with C_3 unnecessary and this part of the test circuit aperiodic. By making the rejection filter F also aperiodic by using, for example, an inductor damped by parallel resistors, measurements at frequencies other than the reference frequency can be carried out relatively simply. If, however, the laboratory or test area is near to industrial premises where high levels of radio noise can be produced, a very high filter impedance is usually required (see Item c) of Sub-clause **1.3.7**).

1.3.7 *Test circuit components*

The components that are used in the test circuit shall meet the following requirements.

a) *High-voltage connections*

The radio noise level produced by the high-voltage connections and terminations of the test circuit shall be insignificant compared with the values to be measured from the test object at the test voltage.

b) *High-voltage transformer* T_1

This transformer shall provide a voltage waveform consistent with the specifications of IEC Publication 60-2: High-voltage Test Techniques, Part 2: Test Procedures.

c) *Rejection filter F*

Filter F shall have an impedance of not less than 20 000 Ω, corresponding to an attenuation of at least 35 dB, in either direction at the measurement frequency.

To be fully effective, the filter should be located as near as possible to the high frequency part of the test circuit. When the filter consists of a tuned circuit (L_1C_1), it should be tuned to the measurement frequency by using, for example, a signal generator connected across the secondary terminals of transformer T_1. Tuning is achieved by varying C_1 to give a minimum reading on the measuring set. The filter impedance may be assessed by measuring its insertion loss by taking the difference in the measuring set readings with the filter short-circuited and then with the short-circuit removed.

At the reference measurement frequency of 0.5 MHz ± 10 %, the value of L_1 should be about 200 µH whereas C_1 should be variable up to a maximum of 600 pF.

d) *Measuring impedance*

The impedance between the live conductor and earth ($Z_s + R_L$ in Figure 4,) shall be 300 ± 40 Ω with a phase angle not exceeding 20°, at the measurement frequency.

A coupling capacitor C_3 (Figure 5) may be used in place of Z_s provided that the capacitance of C_3 is at least five times greater than the capacitance to earth of the test object and its high voltage connection. In practice, a value of 1 000 pF should be satisfactory for C_3.

Capacitor C_3 shall be capable of withstanding the maximum test voltage and have a low partial discharge level at that voltage.

1.3.8 *Measuring set connections*

The more usual method of connecting the measuring set to the test circuit, that is, where the length of cable is less than about 20 m and co-axial cable is used, is shown in Figure 6. Where the length of cable is greater than 20 m, balanced screened cable is used, and this arrangement is shown in Figure 7.

a) *Matching resistor* R_1

To reduce the possibility of errors, due to reflections within the measuring set connections, the co-axial cable, in the case of Figure 6, shall be terminated in its characteristic impedance at each end. Also, in the circuit of Figure 7, the cable/transformer assembly shall be similarly terminated.

The effective input resistance R_m of the measuring set usually provides one matching termination and the other termination is provided by R_1 which shall be of the high stability, non-inductive type.

b) *Series resistor R_2*

To meet the requirement of 300 Ω resistance across the test object, the input resistance R_m of the measuring set in parallel with R_1 has to be increased using a series resistor R_2 which shall be of the high stability, non-inductive type. In the case of a measuring set where R_m is 50 Ω, the value of R_2 should be 275 Ω.

NOTE In some countries other resistance values are assigned to R_L: for example, the National Electrical Manufacturers' Association (NEMA), of the USA, in its Publication 107 (1964), specifies the value of 150 Ω for R_L. Usually a simple conversion can be applied to the results obtained from tests to other specifications. This is because a radio noise source in a test object almost invariably produces a constant current, provided R_L is within the range 100 Ω to 600 Ω and the voltage measured across R_L is simply proportional to its value.

c) *Inductor L_3*

This inductor provides a low-impedance path at power frequency to divert, from the measuring set and its associated components, power frequency currents which flow in C_2 or C_3. At the reference measurement frequency of 0.5 MHz, L_3 shall have a value of at least 1 mH, with a low self-capacitance, to avoid errors exceeding 1 % or 0.1 dB. For safety reasons, L_3 should be robust and have sturdy and secure electrical connections.

d) *Spark gap*

To reduce the possibility of high voltages appearing on the measuring set connections, the provision of a protective spark gap across L_3 is recommended. This spark gap should preferably be of the gas-filled type with a maximum breakdown voltage of 500 V on a power frequency sine wave (see note below).

NOTE In the event of a relatively high power frequency voltage appearing across the spark gap, due for example to a failure of the inductor L_3 or its connections, there could be an increase in the test circuit background noise level, because of corona discharges at the electrodes of the spark gap.

e) *Balanced cable and balun transformers (T_2 and T_3)*

Where the test object is large and/or where very high voltages are involved, the measuring set may have to be located at some distance from the base of (C_2, L_2) or C_3, where R_1 and R_2 are located. Under such conditions the length of co-axial cable shown in Figure 6, may exceed 20 m and, to reduce the possibility of the measurements being affected by interference picked up on this cable, it is recommended that the arrangement shown in Figure 7, should be used.

The balun or coupling transformers T_2 and T_3 should be located close to R_1/R_2 and to the measuring set, respectively, and the connection between the transformers should be made by means of a balanced screened cable. Short lengths of co-axial cable should be used to connect T_2 to R_1/R_2 and T_3 to the measuring set and all these cables should have suitable characteristic impedances to ensure correct matching.

f) *Measuring set*

To comply with C.I.S.P.R. recommendations, the measuring set shall be consistent with the specifications of C.I.S.P.R. Publication 16. If a measuring set with different characteristics is used, a conversion of the results into values which would have been obtained with a C.I.S.P.R. instrument is usually possible, but this can lead to some inaccuracy. This conversion should be carried out as detailed in Sub-clause **1.1**.

1.3.9 *Mounting and arrangement of test object*

The object under test shall be mounted and arranged in accordance with the requirements of the standard applicable to the particular apparatus concerned (for example, IEC Publication 437: Radio Interference Tests on High-voltage Insulators). When no such standard is available, the test object shall be arranged, as far as possible, in the same manner and with the same circuit configuration as exist in service.

The object under test shall be provided with all its normal fittings, such as arcing horns and stress-control fittings, that may affect the distribution of the electric field at the surface of the test object. Where the test object can be in more than one condition, for example a circuit-breaker which can be open or closed, it shall be tested in each of these conditions.

The high-voltage connections to the object under test shall be short and shall not contribute to the measured values of radio noise from the test object nor influence the distribution of the electric field at its surface.

The coupling impedance, L_2 C_2 (or C_3) shall be located near to the test object without significantly disturbing the distribution of the electric field at the surface of the test object.

1.3.10 ***Measurement frequency***

The reference measurement frequency is 0.5 MHz. It is recommended that measurements are made at a frequency of 0.5 MHz ± 10 % but other frequencies, for example 1 MHz, may be used.

1.3.11 ***Checking of the test circuit***

The test circuit shall be arranged so as to permit an accurate measurement of the radio noise level generated by the object under test. Any interference from outside the test circuit, including the supply, or from other parts of the circuit, shall be at a low level and, preferably, at least 10 dB below the level specified for the test object.

With the specified test voltage applied to the circuit, the level of background noise shall be at least 6 dB below the lowest level to be measured. These conditions may be checked by substituting a similar, but noise-free, test object for the object under test.

Background noise levels may be relatively high when the tests are made in an unscreened area, especially when there are industrial premises nearby. When these high levels are of short duration, this condition may be acceptable provided that the quiet periods are of sufficient duration for a reliable measurement to be made and that, during the measurements, the character of the interfering peaks can be clearly distinguished from that of the noise being generated by the test object, possibly by means of an oscilloscope or a loudspeaker.

Interference may also result from broadcast stations which may be overcome by selecting a measurement frequency, within the specific tolerance, which is clear of interference. The use of a resonant circuit L_1C_1, which is correctly tuned, as the rejection filter F, can often be most effective in reducing background noise.

1.3.12 ***Calibration of the test circuit***

The test circuit shown in Figure 5, together with the circuit shown in either Figure 6 or Figure 7, shall be calibrated to obtain the value of the correction factor that shall be applied to the measuring set readings. This factor is the sum of the circuit attenuation and the resistance network factor, both expressed in decibels (dB). Such calibration is required where the test assembly is being used for the first time, or has been re-arranged, or where the test object has been changed to one of a significantly different capacitance. The power supply to the high-voltage transformer should be disconnected during calibration.

a) *Circuit attenuation A*

Before starting the calibration, the rejection filter F shall be tuned, if applicable, as described in Item c) of Sub-clause **1.3.7**, to the particular measurement frequency. A signal generator with an output impedance of at least 20 000 Ω shall then be connected in parallel with the test object, the test circuit being complete, as shown in Figure 5 together with the circuit shown in either Figure 6 or Figure 7. (Such a generator is easily arranged by connecting a 20 000Ω resistor in series with the output of a standard signal generator.) The generator shall be set to deliver a sine wave output of 1 V, at the measurement frequency, which will inject a current of about 50 μA into the test circuit. This current will ensure that, with a C.I.S.P.R. measuring set, its reading will be well in excess of the usual background noise level. This reading, in decibels, of the measuring set shall be noted.

With the settings of the generator unchanged, the test object shall be disconnected from the high-voltage part of the test circuit and connected as shown in Figure 9. The new reading, in decibels, of the measuring set shall also be noted and the difference between the two readings is the circuit attenuation A.

NOTE 1 To avoid removing R_1 and R_2 from the test circuit during the calibration procedure, other high-stability, non-inductive resistors of the same value may be used.

NOTE 2 In Figure 9 the test object may be replaced by an equivalent capacitance, if this is known.

b) *Resistance network factor R*

Levels of radio noise voltage generated by the types of apparatus being considered in this clause are usually expressed in decibels relative to 1 μV across 300 Ω.

Then, if $R_1 = R_m$, the network factor will be as follows:

$$R = 20 \lg \frac{600}{R_1}, \text{ expressed in decibels.}$$

The radio noise level of the object being tested is then given by

$$V\,(\text{dB}/1\ \mu\text{V}/300\ \Omega) = V_m + A + R$$

V_m being the voltage, in decibels relative to 1 μV, indicated by the measuring set and corresponding to its input voltage.

NOTE 1 A less complicated alternative method of overall calibration of the test circuit can be carried out in a single operation if a *calibrated* sine-wave current generator is used. This method involves an accurate measurement of both the output voltage V_0 of the signal generator and the value of a 20 000 Ω resistor R_r in series with the generator output. Then when the signal generator, with the 20 000 Ω series resistor, is connected in parallel with the test object a reading V_1 (μV) appears on the measuring set which corresponds to the current i_1 injected into the circuit:

$$i_1 = \frac{V_0}{R_r} \text{ in microamperes}$$

Under these circumstances, the radio noise level of the apparatus being tested is directly given by:

$$V(\text{dB}/1\ \mu\text{V}/300\ \Omega) = V_m + 20 \lg 300 \frac{i_1}{V_1}$$

where V_m is the voltage, in decibels relative to 1 μV indicated by the measuring set at the time of the test.

NOTE 2 The sine-wave signal generator may be replaced by a pulse generator with a constant frequency spectrum at least up to the measurement frequency. Correspondence of amplitudes between pulse and sinusoidal signals should meet the data included in Sub-clause **2.1** of C.I.S.P.R. Publication 16.

1.3.13 *Test procedure*

Radio noise generated by high-voltage equipment depends mainly on the distribution of the electric fields at the surface of the equipment. Ideally, the distribution in service should be reproduced during tests in the laboratory.

The radio noise level generated by a test object is not entirely determined by a particular value of the test voltage. An hysteresis effect often occurs, with the result that noise may or may not be present at a given test voltage, as it depends on whether this voltage was reached by decreasing or increasing values. Pre-conditioning of the test object, by subjecting it to a voltage which is equal to or greater than the specified test voltage for a specific period of time, can also have an effect on the measured level of radio noise.

The procedure for applying the test voltage should therefore be accurately specified.

The test voltage shall be a sine wave at power-supply frequency and be consistent with IEC Publication 60-2. It shall be applied either:

a) between phases of the object under test (for example a three-phase circuit-breaker), in which case the test voltage is related to the system's line voltage, or

b) between phase and earth (for example a complete insulator string), in which case the test voltage is related to the system's phase voltage.

The test voltage of the object to be tested is usually specified in the standard applicable to the type of object. In the absence of such a specification, the test voltage shall be 1.1 times the nominal voltage of the system or the rated voltage of the equipment ($U/\sqrt{3}$ for apparatus tested with respect to earth). In some cases, the test voltage is agreed between manufacturer and purchaser at a value between 1.1 and 1.4 times the nominal voltage of the system or the rated voltage of the equipment.

A voltage 10 % higher than the specified test voltage should be applied to the object under test and maintained for at least 5 min. The voltage should then be decreased in steps to 30 % of the specified test voltage, raised in steps to the initial value, maintained there for 1 min and, finally, decreased in steps to the 30 % value. Each voltage step should be approximately 10 % of the specified test voltage. At each step a radio noise measurement should be made and the results obtained during the last decreasing run should be plotted against the applied voltage, the curve so obtained being the radio noise characteristic of the test object.

When significant variations are likely to occur in the radio noise level from a number of items of equipment of the same type, the measurements should be done on several samples. Then the typical radio noise characteristic will be the average curve obtained when all the results are taken into account. When the number of samples is sufficient, a level dispersion may also be evaluated. When compliance with limits is required, it may be appropriate to use the statistical method given in Section Nine of C.I.S.P.R. Publication 16.

1.3.14 ***Related observations during the test***

Additional observations may profitably be carried out at the same time as the radio noise measurements, in order to locate any noise sources on the test object and assist in establishing the cause of possible defects. A visual observation, if necessary by means of binoculars in a darkened laboratory, will enable even extremely small points of corona discharge to be located. Such observations may be confirmed by means of photographs with long exposure times, or by means of an image amplifier. If it is impossible to darken the laboratory sufficiently, the points of discharge may be located to some extent by ear or, preferably, by an ultrasonic detector which is much more directional.

1.3.15 ***Data to be given in test report***

In addition to the specification of the apparatus under test, the test report should also give the following data:

— state of the test object:
  - new or already used,
  - clean or polluted (nature and degree of pollution),
  - dry, damp or wet;

— atmospheric conditions:
  - temperature,
  - barometric pressure,
  - relative humidity,
  - presence or absence of rain (standardized artificial rain);

— test circuit, including any difference from the standard C.I.S.P.R. circuit;

— arrangement of the object under test;

— background noise level;

— test voltage with detailed procedure of its application;

— measured radio noise levels, expressed in decibels relative to 1 μV across 300 Ω (these can be given in the radio noise characteristic);

— results of any observations regarding the location of noise sources;

— comparison between the measured levels and any specified limits.

1.4 Statistical evaluation of the radio noise level of a line

C.I.S.P.R. Publication 16 describes statistical sampling methods for establishing the compliance of mass-produced appliances with C.I.S.P.R. limits. The so-called 80 %/80 % rule is based on the application of statistical techniques that have to give the consumer an 80 % degree of confidence that 80 % of the appliances of a type being investigated are below the specified radio noise limit. The method is based on the non-central t-distribution (sampling by variables) and the spirit of the 80 %/80 % C.I.S.P.R. rule is interpreted for overhead lines in that the radio noise level should not exceed the limit for more than 80 % of the time with at least 80 % confidence.

Definitions of readings and sets of measurements:

1) A reading is a single measurement (in decibels), at a given location, under given meteorological conditions. If the meter readings fluctuate, then an average value taken over a period of at least 10 min should be used.

2) Each set of measurements consists of averaging the readings taken, for a given meteorological condition, at three different locations approximately evenly distributed along the line. Not more than one set of measurements should be taken on any particular day for the given meteorological conditions. The three different locations will help to eliminate the effects of local irregularities (for example standing waves), although, as stated in Sub-clause **1.2**, positions of measurement where unrepresentative readings are likely to be obtained should be avoided.

Number of measurements:

1) using the measurement techniques described in Sub-clause **1.2**, at least 15 but preferably 20 or more sets of measurements should be taken.

2) The number of sets of measurements for each weather condition (dry, rain, snow, etc.) must be proportional to the frequency of occurrence of each weather condition for the area.

Compliance with a given limit of noise is judged from the following relationship taken from Section Nine of C.I.S.P.R. Publication 16:

$$\bar{X} + kS_n \leq L$$

where:

L is the permissible upper limit of radio noise

$\bar{X}$ is the mean value of the (n) number of sets of measurements of the radio noise level of the line, namely:

$$\bar{X} = \frac{X_1 + X_2 \ldots + X_i + \ldots X_n}{n}$$

S_n is the standard deviation of the (n) sets of measurements, namely:

$$S_n = \sqrt{\frac{\Sigma_1^n (X_i - \bar{X})^2}{n - 1}}$$

k is the constant depending on (n) and is determined in such a way that the above stated 80 %/80 % rule is satisfied.

The k value to be used for (n) number of sets of measurements is shown in the table below.

n	15	20	25	30	35
k	1.17	1.12	1.09	1.07	1.06

This formula, based on a limited number of samples, is similar to that relating to a Gaussian distribution valid for an infinite number of samples, the samples being represented by sets of measurements.

In the formula, S_n can be compared with the standard deviation relating to an infinite number of samples and k depends on both the required confidence (80 %/80 %) and on the number of samples. The lower the number of samples the higher the value of k becomes for any percentage specified to meet the limit, with a given confidence.

Studies indicate that even for a non-Gaussian distribution, the use of the above statistical method does not introduce a significant error provided that at least 15 but preferably 20 or more sets of measurements are used in the evaluation.

2 Methods for derivation of limits

2.1 Introduction

The C.I.S.P.R. has for many years considered the question of limits of radio noise from overhead power lines and high-voltage equipment in order to safeguard radio and television broadcast reception. The degree of annoyance caused by radio noise is determined by the signal-to-noise ratio at the receiving installation. For similar subjective annoyance, the signal-to-noise ratio depends on the nature of the noise source. Based on a required signal-to-noise ratio, many factors affect the acceptable level of noise, such as minimum signal level to be protected, minimum distance between power line and receiving location, effects of weather, etc. Further difficulties exist in specifying the conditions for verifying compliance with limits. For example, views are divided on whether measurements should be carried out in fair weather, foul weather, or both. Practically every major factor is subject to statistical variation. It is recognized that international discussions cannot fully resolve these problems. Some countries have, however, laid down mandatory standards on limits of interference from power lines.

There is general agreement by countries participating in C.I.S.P.R. that guidance should be given by it on a simple and effective method for deriving limits on a national basis, taking into account particular conditions the regulatory authority may wish to adopt. Furthermore, it is agreed that the method of deriving limits should be illustrated by examples based on reasonable signal levels, adequate receiver installations and on practical and economical power line designs. The method should enable assessment of the effects of power lines on reception under any particular conditions.

Since a number of arbitrary assumptions about random parameters must be made, which may differ from actual conditions, and since economic factors must also be considered, recommended limits cannot assure 100 % protection to 100 % of the listeners or viewers. This fact is generally accepted in standardization.

2.2 Significance of C.I.S.P.R. limits for power lines and high-voltage equipment

C.I.S.P.R. Recommendation 46/1 "Significance of C.I.S.P.R. Limits" [67][2)] and Section Nine of C.I.S.P.R. Publication 16, specify a statistical basis for analysing test data to determine compliance with a C.I.S.P.R. limit for mass-produced appliances.

In the case of noise from power lines and high-voltage equipment, this criterion is not directly applicable. It is, however, possible to relate it to the statistical distribution of noise due to the variation of atmospheric conditions. For power lines and equipment, the C.I.S.P.R. limit may be interpreted as the noise level not exceeded for 80 % of the time. However, as is discussed in Sub-clause **1.4**, this application of the C.I.S.P.R. 80 %/80 % rule involves a larger number of measurements than is specified in Recommendation 46/1. It must also be realized that an 80 % level for conductor corona noise for power lines in moderate climates will usually be a foul-weather level, whereas for dry climates it will usually be a fair-weather level. Regulatory authorities should keep this fact in mind when deciding on adoption of the 80 % level.

A different criterion such as average, fair-weather, noise level: maximum, fair-weather, noise level: or even the heavy rain noise level could also be the basis for establishing limits.

2.3 Technical considerations for derivation of limits for lines

2.3.1 ***Basic approach***

The basic requirement is to obtain an adequate signal-to-noise ratio at the receiving installation for satisfactory reception of broadcast signals. When establishing regulations, it will be the responsibility of the regulatory authority to determine the minimum signal strengths to be protected and the signal-to-noise ratio that will give satisfactory reception. This publication presents the latest information on acceptable signal-to-noise ratios and gives some information on minimum signal levels to be protected. It also shows how the protected signal level and the required signal-to-noise ratio can be combined with the noise level at a reference distance of 20 m from the nearest conductor of the power line to develop a "protected distance". This protected distance represents the minimum distance from the line required to protect the minimum broadcast signal for a certain percentage of the time. For example, if the 80 % level is chosen as the basis for the radio noise, then this protected distance will be the minimum distance from the line at which the minimum protected signal can be received 80 % of the time with an acceptable signal-to-noise ratio. If the average fair weather noise level is the basis for establishing limits, then this protected distance will be the minimum distance from the line at which the minimum protected signal level can be received for 50 % of the time during fair weather with an acceptable signal-to-noise ratio. Similar logic would apply for any other percentage, taken on an all-weather noise distribution curve, or for any other weather condition, for example, steady rain (in this case, reception would be satisfactory 95 % of the time, at least in moderate climates).

It should be appreciated that at most locations the signal level will be higher than the minimum and that advantage can sometimes be taken of the directional properties of certain types of receiving aerial to improve the signal-to-noise ratio. On the other hand, there will be cases where the distance between the power line, or high-voltage equipment, and the receiving location will be less than the protected distance. On a statistical basis these factors will often tend to balance each other in such a way as to provide adequate reception even in cases falling within the protected distance. For those so placed who suffer interference, correction techniques may be employed such as remote aerials or connection to cable systems.

[2)] The figures in square brackets refer to "Bibliography and references", page 58.

2.3.2 *Scope*

2.3.2.1 *Power systems considered*

The radio noise limits discussed in this clause apply to the power system as a whole and not to its individual components such as transformers, insulators, etc. The method of measurement of the noise level of a component is discussed in Sub-clause **1.3** and the relation of this level to that which it would produce 20 m from the nearest conductor of a power line is discussed in Sub-clause **6.2** of C.I.S.P.R. Publication 18-1. All a.c. lines and substations operating at voltages within the range 1 kV to 800 kV are included. At the present time there is insufficient information to allow examples to be provided of the derivation of limits for d.c. lines, although the main principles could be the same. This matter is still under consideration.

The noise limits are based on lateral attenuation laws applicable to typical power lines and on the appropriate C.I.S.P.R. measuring methods and instruments referred to in Clause **1**. No well-established data are presently available for substations. For simplicity, however, the same laws may be used as for lines, the reference distance being taken as 20 m from the perimeter fence of the substation. It should be noted that only persistent noise from substations is considered. Transient noise, such as that due to interruption of a power circuit, is not included.

2.3.2.2 *Frequency range*

The frequency range is from 0.15 MHz to 300 MHz, covering specifically the a.m. broadcast bands between 0.15 MHz and 1.7 MHz and the v.h.f. television and f.m. radio bands between 47 MHz and 230 MHz. The intent is to provide protection to "reasonable" signal levels of these services. Since power lines normally produce negligible interference to broadcast reception above 300 MHz and since there is only limited information on noise levels at these frequencies, the bands above 300 MHz are not included at this time.

The definition of "reasonable" will vary with the type of service and part of the world. The International Telecommunications Union (ITU) considers three regions (1,2 and 3). Regions 1 and 3 are further divided into three zones (A, B and C) based on climatic conditions. Figure 10, shows these regions and zones. Within each region and zone, there are specific transmitter power levels, minimum protected signal levels, required co-channel and adjacent channel protection ratios, etc.

In particular the low and medium frequency broadcast bands 0.15 MHz to 0.28 MHz and 0.5 MHz to 1.7 MHz are regulated by the ITU. However, existing practices regarding minimum signal levels to be protected and also regarding protection ratios often differ from the latest recommendations of the ITU. In North America the 0.5 MHz to 1.7 MHz band is regulated by the North American Regional Broadcasting Agreement (NARBA). It should be noted here that some of the differences result from differences in broadcasting philosophies. In Europe, for example, it is usual to have a few omnidirectional transmitters of high power to cover an entire country. In North America, on the other hand, there is a multitude of individual stations, often with highly-directional aerial arrays aiming a signal at a particular city or region of the country. Transmitter power is usually limited to 50 kW and protected received signal levels are generally lower than those specified in Europe.

NOTE The upper and lower limits of the various frequency bands, used for broadcasting and given here, are approximate values. Exact values vary from one region to another and are subject to periodic revisions. (See reference [62] for more details.)

2.3.3 *Minimum broadcast signal levels to be protected*

Individual national authorities should determine the minimum signal levels to be protected from power line noise related to appropriate weather conditions. For the low frequency and medium frequency bands, the ITU [63] has recommended minimum field strengths necessary to overcome natural noise (atmospheric noise, cosmic noise, etc.). For broadcast planning purposes, the ITU has also recommended for information only, nominal usable field strengths. Appendix C gives recommended values for both the minimum and the nominal usable field strengths.

Since natural noise levels vary with time and geographical location, signal levels below these values can sometimes be received satisfactorily and at other times unsatisfactorily, irrespective of power line or other man-made noise.

For the v.h.f. bands, the International Radio Consultative Committee (CCIR) recommended minimum signal levels for Region I are as follows:

Frequency band	Minimum signal strength
Television band I, 47 MHz to 68 MHz	48 dB (1 µV/m)
F.M. radio band II, 87 MHz to 108 MHz	48 dB (1 µ V/m) (for mono) 54 dB (1 µV/m) (for stereo)
Television band III, 174 MHz to 230 MHz	55 dB (1 µV/m)

In North America, signal levels at the edge of the service area of a broadcasting station are specified by NARBA and other standards [64 to 66]. These levels are given in Appendix D.

It is generally accepted that when criteria for the protection of TV in bands I and III have been fixed, f.m. monoaural radio is automatically protected. The protection requirements for f.m. stereo radio are under consideration. Similarly, the intermediate bands, such as short wave, will automatically be protected by the medium wave broadcast band protection. However, in certain cases, there may be telecommunication services requiring different protections. These should be taken into account by national authorities when limits are being considered.

It should be borne in mind that all of these minimum signal levels are related to protection against interference from other radio signals or from natural noise. Interference from power line noise has not been considered.

With the widely differing values adopted for usable signal levels for different zones of the world, daytime and night time, the term "reasonable signal level" has to be established with regard to the factors relevant to the different levels. It is inevitable that if low levels are adopted, radio noise from power lines should be viewed in comparison with other sources of interference and the protected distance between the power line and receiver should be increased and/or the acceptable signal-to-noise ratio reduced.

2.3.4 ***Required signal-to-noise ratio***

2.3.4.1 *Radio broadcasting*

No exact recommendations as to acceptable signal-to-noise ratios have yet been devised for noise from power lines. For planning purposes, the ITU recommend a wanted-to-interfering signal ratio of 30 dB. NARBA levels are based on a ratio of 26 dB.

For similar ratios, power line noise may represent somewhat less objectionable interference than does co-channel interference.

The technical literature contains results of a number of investigations of the required signal-to-noise ratio for satisfactory reception in the presence of power line noise. These are summarized in Appendix E. The required ratios for various qualities of reception from "entirely satisfactory" to "speech unintelligible" are provided. National regulatory authorities may specify the quality of reception they wish to protect. It should be borne in mind that the signal-to-noise ratio depends largely on the receiver bandwidth. The ratios given in Appendix E are based on the signal being measured on an average or r.m.s. reading meter and the noise being measured on a C.I.S.P.R. meter with a quasi-peak detector. For a.m. reception, the C.I.S.P.R. meter has a 9 kHz bandwidth. The level of an a.m. broadcast signal measured on the C.I.S.P.R. meter will be about 3 dB higher, depending on the modulation amplitude, since the quasi-peak detector produces an output which approaches the peak of the modulation envelope. This effect will, of course, not apply if the measurements are made on an unmodulated signal.

2.3.4.2 *Television broadcasting*

The required signal-to-noise ratios for television reception are less definite than those for radio. For the European television standards, 40 dB appears to be generally acceptable (the bandwidth of the C.I.S.P.R. meter being 120 kHz). However, tests carried out in the United Kingdom with a positive modulated black and white picture showed that this value could be reduced by up to about 5 dB. For the North American television standards, several limited tests have suggested 40 dB for black and white television [58]. Tests on colour television are currently being carried out. Further consideration of all these issues is required.

The repetition rates of noise pulses due to corona and to gap-type discharges may differ considerably. This may have a large influence on the degree of interference produced on a television picture. Although there is not much data available, this should be considered when establishing acceptable signal-to-noise ratios for television reception.

2.3.5 *Conversion of measured values*

2.3.5.1 *Attenuation laws*

The rate of lateral attenuation of radio noise, for distances between about 20 m and 100 m from the nearest conductor of a line, varies in different frequency ranges and also depends on the configuration of the line. The following approximate values should provide satisfactory results:

— 0.15 MHz to 0.4 MHz, noise level decreases as $D^{-1.8}$

— 0.4 MHz to 1.7 MHz, noise level decreases as $D^{-1.65}$

— 30 MHz to 100 MHz, noise level decreases as $D^{-1.2}$

— 100 MHz to 300 MHz, noise level decreases as $D^{-1.0}$

Presumably the factor 1.65 is somewhat valid between 1.7 MHz and 30 MHz. The information for the 30 MHz to 300 MHz band is based on a few measurements, but it must be appreciated that the mechanism and also the attenuation law are dependent on the type of noise source, for example conductor corona or gap-type discharges at fittings.

The noise levels referred to 20 m from the nearest conductor of a line may, therefore, be corrected to the protected distance, using the following correction formulae:

0.15 MHz to 0.4 MHz $$E_p = E_0 - 36 \lg \frac{D_p}{20}$$

0.4 MHz to 1.7 MHz $$E_p = E_0 - 33 \lg \frac{D_p}{20}$$

where:

E_p is the radio noise level at protected distance, dB (1 μV m)
E_0 is the radio noise level at 20 m. dB (1 μV m)
D_p is the protected distance (m)

NOTE Numerous measurements in the medium frequency band have demonstrated that, on average, the noise level decreases as $D^{-1.65}$ close to the line (see Sub-clause **4.2** of C.I.S.P.R. Publication 18-1). For greater distances, however, some measurements have shown that it decreases as D^{-1}. For any distance greater than about 100 m, more accurate value for the noise level E_p may be given by:

0.4 MHz to 1.7 MHz $$E_p = E_0 - 23 - 20 \lg \frac{D_p}{100} \qquad D_p > 100 \text{ m}$$

There is a degree of uncertainty as to the lateral distance beyond which this formula applies. In most cases, however, at distances beyond 100 m the noise level will be so low that broadcast reception will not be affected.

2.3.5.2 *Distance of measurement*

Whenever possible, measurements should be made at a distance of 20 m from the nearest conductor. When this is not possible, the above formulae may be used to convert measured values taken at other distances to the standard C.I.S.P.R. distance of 20 m. Measurements should also be taken at distances other than 20 m for verification purposes. In all cases, measured profiles of lateral attenuation are greatly preferable to the use of correction formulae (see also Sub-clause **1.2.3**).

2.4 Methods of determining compliance with limits

The approximate radio noise level due to conductor corona may be predicted for a power line by use of an empirical formula, such as is presented in Sub-clause **2.2** of C.I.S.P.R. Publication 18-3 or with the help of the catalogue (Appendix B of C.I.S.P.R. Publication 18-l). Reliable prediction of noise levels is important as no corrections of line design or construction can economically be made after the line has been built. Once the line is in service, there are several alternative measurement procedures by which this predicted level may be verified. The choice of method will depend on the length of time available for the measurements and on the degree of accuracy required.

2.4.1 ***Long-term recording***

This is the most precise method for evaluating the noise level produced by a power line but it takes a long time to obtain the results. A noise-recording station is set up close to the power line under investigation and continuous measurements are made for at least one year. The suitability of the recording site must be checked by means of measurements at various points along the line. The results are plotted on a probability graph of the type shown in Figure 3 of Publication 18-1. At the percentage of time that has been selected for specifying the noise, the level is read from the graph.

2.4.2 ***Sampling method***

This is a practical and accurate method that follows the spirit of C.I.S.P.R. Recommendation 46/1. At least 15 or preferably 20 or more individual sets of measurements of noise level are carried out at various locations along the line and under various weather conditions. The selection of different weather conditions should be more or less in proportion to the percentage of time each weather condition exists in the area of the power line. These measurements are then analyzed to give the noise level that will not be exceeded for 50 %, 80 %, or 95 % of the time, with an 80 % confidence, according to the chosen criterion (see Sub-clause **2.3.1**).

The sampling method is fully described in Sub-clause **1.4** for the case where the chosen criterion is the 80 % level.

2.4.3 ***Survey methods***

If time or any other reason does not allow either of the above methods to be used, the alternative of making measurements in fair weather or heavy rain may be considered. This can be adequate when conductor corona is the main noise source and when the radio noise distribution curves for the particular type of line for the all-year-round weather conditions are available. These curves could, for instance, have been obtained from previous accurate measurements on the actual or on the same type of line under similar climatic conditions. Preferably three distribution curves should be available; 1) under fair weather conditions, 2) under heavy rain and 3) under all-year-round weather conditions. Statistical distributions are discussed in Sub-clause **4.2.3** of C.I.S.P.R. Publication 18-1. It should be noted that the methods outlined in the two following paragraphs do not apply to lines below 72.5 kV where conductor corona is not the major source of radio noise.

Fair-weather measurements have to be made at various locations along the line and at different times. From the results, the 50 % fair-weather level is deduced and used as a reference in the set of curves mentioned above. From the curves the all-weather 80 % value can then be assessed. The success of this method is dependent on the reliability of the distribution curves. In general the 80 % all-weather value is from 5 dB to 15 dB higher than the 50 % fair-weather value, depending on the climate.

Since the radio noise level due to conductor corona is relatively stable and reproducible during heavy rain, these measurements are not required to be taken at separate times. Foul-weather measurements should also be made at various locations along the line. The 50 % steady, heavy, rain level is deduced from the results of the measurements and used as a reference in the set of distribution curves to assess the 80 % all-weather level. Here also the success of the method is dependent on the reliability of the distribution curves, although it is considered that the assessment of the 80 % all-weather value from the heavy-rain measurements is more reliable than the assessment from the fair-weather measurements. In general, the 80 % all-weather level is about 5 dB to 12 dB lower than the 50 % steady, heavy, rain level.

2.4.4 ***Alternative criterion for acceptable noise level***

One of the alternative criteria for acceptable noise levels, as discussed in Sub-clause **2.2**, may be used. If, for example, the average fair-weather noise level is chosen, then a series of measurements should be carried out during typical fair weather conditions. At least three measurements should be carried out at three different locations along the line. If time permits, this should be repeated on another day. The average of all the measurement values will be considered to represent the average fair-weather noise level of the line.

2.5 Examples for derivation of limits

2.5.1 *Radio reception*

Examples of the calculation of limits are given below based on the assumptions discussed in the preceding sub-clauses. Limits could also be calculated for different assumptions in respect of signal level, signal-to-noise ratio and distance from a power line. Conversely, for a given level of noise, the minimum acceptable distance, for satisfactory reception of a given signal strength, could be calculated.

It should be borne in mind that the lateral attenuation laws quoted are average values. They depend on factors relating to both line design and local conditions. They may change with distance and should not be used for distances materially beyond those assumed in this sub-clause.

Furthermore, it should be remembered that radio-noise is generally measured at a frequency of 0.5 MHz. If a signal at a specified broadcast frequency is to be protected, the measured values should be corrected for the given frequency according to Sub-clause **4.2.1** and Figure B12 of C.I.S.P.R. Publication 18-1. For example, at 1 MHz, the noise level would be about 5 dB to 6 dB lower.

2.5.1.1 *Principle*

There are four parameters involved in the specification of radio noise limits (see Figure 11.):

— the minimum signal level to be protected:

— the minimum acceptable signal-to-noise ratio:

— the reference noise level, 20 m from the nearest conductor, during prescribed weather conditions;

— the "protected distance" ,that is, the minimum distance from the line at which the signal can be satisfactorily received.

If any three of these parameters are specified, the fourth can be determined. Two examples will demonstrate this.

2.5.1.2 *Example 1*

If the value of the noise level at 20 m from the nearest conductor, the protected signal level and the required signal-to-noise ratio are all known, the protected distance from the power line for satisfactory radio reception in the low and medium frequency bands may be calculated from the formula given in Appendix F.

In the m.f. band, this formula is accurate for distances up to about 100 m.

As an example, the distance from a given power line at which a signal of 72 dB (1 μV/m) at 1 MHz may be received with a signal-to-noise ratio of 35 dB is required. The line noise measured by the standard C.I.S.P.R. method is found to be 50 dB (1 μV/m). The following calculation is made:

Protected signal level at 1 MHz	S_p = 72 dB (1 μV/m)
Required signal-to-noise ratio	R_p = 35 dB
Acceptable noise level at protected distance from line	$N_p = S_p - R_p$ N_p = 37 dB (1 μV/m)
Measured noise level 20 m from nearest conductor at 0.5 MHz	50 dB (1 μV/m)
Noise level at 1 MHz	E_0 = 50–6 = 44 dB (1 μV/m)
(The 6 dB correction comes from Figure B12 of C.I.S.P.R. Publication 18-1.)	
Protected distance	$D_p = 10^{\left(\frac{44+35-27}{33}+1.3\right)}$

Therefore D_p = 32 m from nearest conductor.

2.5.1.3 *Example 2*

In this second example a broadcast signal at 1 MHz, 65 dB (1 µV/m), is to be protected with a signal-to-noise ratio of 30 dB at distances greater than 100 m from the power line. The acceptable reference noise level at 20 m is calculated as follows:

Protected signal level at 1 MHz	65 dB (1 µV/m)
Acceptable noise level at protected distance from line	65 – 30 = 35 dB (1 µV/m)
Attenuation from 20 m to 100 m	$33 \lg \frac{100}{20} = 23$ dB
Acceptable reference noise level at 20 m from nearest conductor, at 1 MHz	35 + 23 = 58 dB (1 µV/m)
Therefore, acceptable reference noise level at C.I.S.P.R. reference frequency (0.5 MHz)	58 + 6 = 64 dB (1 µV/m)
(The 6 dB correction comes from Figure B12 of C.I.S.P.R. Publication 18-1.)	

2.5.2 ***Television reception, 47 MHz to 230 MHz***

This is under consideration. Insufficient information is presently available to permit presentation of meaningful examples.

2.6 Additional remarks

Most field tests to date have been carried out in the low and medium frequency bands. Therefore, any data presented on the v.h.f. band should be considered as provisional and major conclusions should not be based on it. This whole subject is still under consideration.

If limits are based on noise levels measured and statistically evaluated in accordance with Sub-clause **1.4**, they also represent statistical values not exceeded for 80 % of the time. For conductor corona noise it should be noted that these values are significantly higher than average fair-weather levels. This factor should be taken into account when these values are compared with standards for typical fair-weather conditions laid down in various countries.

As in the case of other sources of possible interference for which C.I.S.P.R. limits exist, examples of limits presented here are based on the requirements for the protection of reception for the large majority of listeners or viewers under conditions prevailing at the majority of sites during most of the time. Such values cannot cater for the few exceptional cases where a number of unfavourable factors coincide.

Practice has shown that acceptable noise levels in this clause can be met with well-maintained power lines of adequate design and construction. Indeed, considerably lower levels are found on many operational lines where requirements other than radio noise lead to designs with larger conductor sizes (for example high current-carrying capacity). It is considered that the methods of deriving limits indicated in this clause represent good engineering practice and could serve as the basis for establishing such limits.

2.7 Technical considerations for derivation of limits for line equipment and substations

The principle for establishing limits of radio noise voltage for line insulators and fittings and substation plant and fittings in the l.f. and m.f. bands shall be that their contribution to the aggregate noise level of a transmission line is negligible. This is applicable to a.c. lines whose conductors are subjected to surface gradients of about 12 – 14 kV/cm or higher. This principle pre-supposes coordination between noise produced by insulators and fittings on the one hand and noise produced by line conductor corona on the other hand. For other a.c. lines, with a lower surface gradient, the noise voltage for line equipment shall be at least as low as the noise voltage for equipment used on lines with a surface gradient of about 12 kV/cm. This principle is applicable to d.c. lines but no figures of gradient are quoted as the relationship between conductor corona noise and noise produced by insulators and fittings is not well established (see Sub-clause **8.2** of C.I.S.P.R. Publication 18-1) the corona noise being higher in dry weather and lower in wet weather. Sub-clause **1.3** describes the C.I.S.P.R. method of radio noise measurement in the laboratory. Sub-clause **6.2** of C.I.S.P.R. Publication 18-1 gives the correlation between the radio noise voltage measured in microvolts, in the C.I.S.P.R. test circuit, due to any noise source (Sub-clause **1.3**) and the radio noise field on site, in microvolts per metre, measured in accordance with the method described in Sub-clause **1.3**.

For frequencies above a few megahertz, the correlations between the radio noise voltage and the corresponding radio noise field given in Sub-clause **6.2** of C.I.S.P.R. Publication 18-1 do not apply. This means that no principle for establishing limits for frequencies above the m.f. band can be laid down at present.

The radio noise field near a substation, generated by noise sources within the substation may be the aggregation of the direct radiated field and the guided field due to currents injected into an overhead line serving the substation. At present, insufficient data are available on the radiated component and therefore only the injected currents will be discussed. Coordination between the injected noise currents and the currents produced by line conductor corona applies in this case also.

2.7.1 ***Current injected by line components and fittings***

To evaluate the relative influence of insulators and conductors, it is sufficient to compare the current generated by a complete insulator set with the aggregate current I_L generated by a span of one phase conductor of the line. If the current generated by the insulator set is less than I_L, its contribution to the aggregate noise field of the line will be small; if it is equal to I_L, the increase in level due to the insulators will be approximately 3 dB; if it is greater than I_L the noise field of the line will be determined mainly by the effect of the insulators.

If the limit of the current of the insulator set is specified as $I_L/3$, that is 10 dB below the current I_L, the increase in the aggregate noise field will be about 0.5 dB. This increase is too small to be measured in practice.

In addition to insulator sets, other components and fittings such as spacers, vibration dampers and aircraft warning devices have to be considered. If for any one of these types of component or fitting there are N items per span the radio noise level per item should not be greater than $1/\sqrt{N}$ times the level for an insulator set.

The aggregate radio noise current per span from all these components and fittings should, according to experience, be determined by quadratic summation of the individually measured currents.

2.7.2 ***Current injected by substation equipment***

The equipment is considered as a generator of radio noise current, as indicated in Sub-clause **6.2** of C.I.S.P.R. Publication 18-1. The problem consists in studying the propagation of the injected current along the line, that is, the attenuation and distortion of the guided electromagnetic field associated with this current. To do this, modal analysis is employed.

A substation normally has more than one associated line each with one or more circuits. For determination of the current injected into one of the circuits, it is necessary to know not only the impedance of all circuits but also the impedance of the substation equipment, consisting of busbars, measuring devices, transformers, capacitors, cables, etc., as seen from the apparatus acting as a current source. The current in the circuit under consideration can then be calculated.

For the worst case, the impedance of the substation equipment could be assumed to be infinite. Then for N pieces of apparatus, each producing the same value of noise current I_0, and for n outgoing circuits, the current injected into a circuit is

$$I = I_0 \frac{\sqrt{N}}{n}$$

Clearly the case of a substation with only one circuit is the most unfavourable.

If the current calculated in this way is equal to the value of the current produced by line conductor corona, the increase in the radio noise field at the substation terminal tower will be approximately 3 dB but after 1 or 2 km the additional noise current, and consequently the increase in the field, will be insignificant.

2.7.3 ***Practical derivation of limits in the l.f. and m.f. bands***

a) *Line components and fittings*

The rigorous procedure is as follows: starting from the graph of the excitation function and the matrix of the line capacitances (see Sub-clause **5.2** of C.I.S.P.R. Publication 18-1), the current I injected per unit length of a phase conductor is calculated. To pass from this elemental current I to the aggregate current, generated by a span of length L, the law of quadratic summation is applied:

$$I_L = I\sqrt{L}$$

When comparing the current generated by a complete insulator set with the aggregate current I_L, it is advisable to include a margin of 10 dB in order to ensure a negligible increase in the aggregate level of the noise field. The value of insulator noise current used in the comparison should be the maximum obtained under the normal range of weather conditions for the area over which the proposed line will run.

For practical purposes, a simple relationship can be derived from the formula (6) given in Sub-clause **6.2.1.2** of C.I.S.P.R. Publication 18-1. The current I from a single insulator set should not exceed the value given by:

$$I = E - 27 - K_1$$

where:

I is in dB (1 μA)

E is the permissible radio noise field strength during reference weather conditions, in dB (1 μV/m), at a distance of 20 m from the nearest conductor of the line

K_1 is the difference in decibels between the conductor corona noise level in the reference weather conditions and that in weather conditions in which the maximum insulator noise level is generated

The formula includes the above-mentioned margin of 10 dB.

b) *Substation plant and fittings*

The total current I injected into a line by a substation should not exceed the value given by:

$$I = E - 12 - K_2$$

where:

I is in dB (1 μA)

E is the permissible radio noise field strength during reference weather conditions, in dB (1 μV/m), at a distance of 20 m from the nearest conductor of the line, derived from the relevant example in Sub-clause **2.5**

K_2 is the difference in decibels between the conductor corona noise level in the reference weather conditions and that in weather conditions in which the maximum substation noise level is generated

This formula is derived from formula (4) given in Sub-clause **6.2.1.2** of C.I.S.P.R. Publication 18-1 for a conductor height h of 15 m and a depth of penetration into the ground P_g of 7 m. No provision has been made for a margin.

At the junction between a line and substation busbars there will usually be an impedance mismatch. This may create standing waves of radio noise on the first few kilometres of the line resulting in a variation of up to ± 6 dB close to the substation. This is not taken into account in the formulae given above.

NOTE 1 These limits are derived from the permissible radio noise field strength for a line.

NOTE 2 The main difficulty in the practical application of this principle is to simulate the service conditions for the test objects in the laboratory. As mentioned in Sub-clause **6.3** of C.I.S.P.R. Publication 18-1, there is at present no agreed procedure for simulating in the laboratory the more common service conditions but the matter is under consideration. Meanwhile, it is proposed that measurements should be made on equipment in a situation closely related to service conditions.

NOTE 3 Limits for individual items of plant, for example switch disconnectors, circuit breakers, etc., cannot be specified in this publication as these items are the responsibility of other bodies. However, the effect of these individual items, when in their service environment, must be in accordance with the limits discussed above.

3 Methods for derivation of limits for the radio noise due to HVDC lines

The CISPR has for many years considered the question of limits of radio noise from overhead power lines and high-voltage equipment in order to safeguard radio and television broadcast reception. The degree of annoyance caused by radio noise is determined by the signal-to-noise ratio at the receiving installation. For similar subjective annoyance, the signal-to-noise ratio depends on the nature of the noise source. Based on a required signal-to-noise ratio, many factors affect the acceptable level of noise, such as minimum signal level to be protected, minimum distance between power line and receiving location, effects of weather, etc. Further difficulties exist in specifying the conditions for verifying compliance with limits. For example, views are divided on whether measurements should be carried out in fair-weather, foul weather, or both. Practically every major factor is subject to statistical variation. It is recognized that international discussions cannot fully resolve these problems. Some countries have, however, laid down mandatory standards on limits of interference from power lines.

There is general agreement by countries participating in CISPR that guidance should be given by it on a simple and effective method for deriving limits on a national basis, taking into account particular conditions the regulatory authority may wish to adopt. Furthermore, it is agreed that the method of deriving limits should be illustrated by examples based on reasonable signal levels, adequate receiver installations and on practical and economical power line designs. The method should enable assessment of the effects of power lines on reception under any particular conditions.

Since a number of arbitrary assumptions about random parameters must be made, which may differ from actual conditions, and since economic factors must also be considered, recommended limits cannot assure 100 % protection to 100 % of the listeners or viewers. This fact is generally accepted in standardization.

3.1 Significance of CISPR limits for power lines and high-voltage equipment

CISPR Recommendation 46/1 "Significance of CISPR Limits" and Section 9 of CISPR 16, specify the statistical basis for analysing test data to determine compliance with a CISPR limit for mass-produced appliances.

In the case of noise from power lines and high-voltage equipment, this criterion is not directly applicable. It is, however, possible to relate it to the statistical distribution of noise due to the variation of atmospheric conditions. For power lines and equipment, the CISPR limit may be interpreted as the noise level not exceeded for 80 % of the time. However, as it is discussed in 1.4, this application of the CISPR 80 %/80 % rule involves a larger number of measurements than is specified in Recommendation 46/1. It must also be realized that an 80 % level for conductor corona noise for d.c. lines will always be a fair-weather level for all climates, whereas for a.c. lines, the 80 % level in moderate climates will usually be a foul-weather level, and for dry climates, it will usually be a fair-weather level.

Figure 12, which shows typical annual all-weather radio noise at 0,5 MHz cumulative amplitude distributions for an a.c. line and a bipolar d.c. line in moderate climates, illustrates this difference between corona noise from a.c. and d.c. lines. Regulatory authorities should keep these facts in mind when deciding an adoption of the 80 % level.

Other criteria, such as average fair-weather noise levels or possibly maximum fair-weather noise levels, could also be the basis for establishing limits for high-voltage direct current (HVDC) lines. Foul-weather noise is normally lower (**8.2** of CISPR 18-1); therefore, the fair-weather noise level (50 %) is higher than the foul-weather noise level, but the difference is moderate. The fair-weather noise level should always be the basis for establishing limits for HVDC lines.

3.2 Technical considerations for derivation of limits for lines

3.2.1 *Basic approach*

The basic requirement is to obtain an adequate signal-to-noise ratio at the receiving installation for satisfactory reception of broadcast signals. When establishing regulations, it will be the responsibility of the regulatory authority to determine the minimum signal strengths to be protected and the signal-to-noise ratio that will give satisfactory reception. This publication presents the latest information on acceptable signal-to-noise ratios and gives some information on minimum signal levels to be protected. It also shows how the protected signal level and the required signal-to-noise ratio can be combined with the noise level at a reference distance of 20 m from the nearest positive conductor of the power line to develop a "protected distance". This protected distance represents the minimum distance from the line required to protect the minimum broadcast signal for a certain percentage of the time. For example, if the 80 % level is chosen as the basis for the radio noise, then this protected distance will be the minimum distance from the line at which the minimum protected signal can be received 80 % of the time with an acceptable signal-to-noise ratio. If the average fair-weather noise level is the basis for establishing limits, then this protected distance will be the minimum distance from the line at which the minimum protected signal level can be received for 50 % of the time during fair-weather with an acceptable signal-to-noise ratio.

It should be appreciated that at most locations the signal level will be higher than the minimum, and that advantage can sometimes be taken of the directional properties of certain types of receiving aerial to improve the signal-to-noise ratio. On the other hand, there will be cases where the distance between the power line, or high-voltage equipment, and the receiving location will be less than the protected distance. On a statistical basis, these factors will often tend to balance each other in such a way as to provide adequate reception even in cases falling within the protected distance. For those so placed who suffer interference, correction techniques may be employed, such as remote aerials or connection to cable systems.

3.2.2 *Scope*

It must be noted that only radio interference from HVDC overhead power lines and converter stations is here considered, which is produced by corona discharges on the surface of conductors and high-voltage equipment. Radio interference produced by turn-on and turn-off sequences in the valves of a converter station is not taken into account. The power systems and the frequency ranges considered by this publication are indicated in the following two subclauses.

3.2.2.1 *Power systems considered*

The radio noise limits discussed in this subclause apply to the power system as a whole and not to its individual components such as transformers, insulators, etc. The method of measurement of the noise level of a component is discussed in **1.3** of CISPR 18-2, and the relation of this level to that which it would produce in service at a distance of 20 m from the nearest positive conductor of a power line is discussed in **6.2** of CISPR 18-1. Clause **3** applies to all HVDC lines operating at voltages from 1 kV to ± 750 kV.

The noise limits are based on lateral attenuation laws applicable to typical power lines and on the appropriate CISPR measuring methods and instruments. No well-established data are presently available for converter stations. For simplicity, however, the same laws may be used as for lines, the reference distance being taken as 20 m from the perimeter fence of the converter station. It should be noted that only persistent noise from converter stations is considered. Transient noise, such as that due to interruption of a power circuit, is not included.

3.2.2.2 *Frequency range*

The frequency range is from 0,15 MHz to 300 MHz, covering specifically the a.m. broadcast bands between 0,15 MHz and 1,7 MHz and the v.h.f. television and f.m. radio bands between 47 MHz and 230 MHz. The intent is to provide protection to "reasonable" signal levels of these services. Since power lines normally produce negligible interference to broadcast reception above 300 MHz, and since there is only limited information on noise levels at these frequencies, the bands above 300 MHz are not included at this time.

The definition of "reasonable" will vary with the type of service and part of the world. The International Telecommunications Union (ITU) considers three regions (1, 2 and 3). Regions 1 and 3 are further divided into three zones (A, B and C) based on climatic conditions. Figure 10 shows these regions and zones. Within each region and zone, there are specific transmitter power levels, minimum protected signal levels, required co-channel and adjacent channel protection ratios, etc.

In particular, the low and medium frequency broadcast bands 0,15 MHz to 0,28 MHz and 0,5 MHz to 1,7 MHz are regulated by the ITU. However, existing practices regarding minimum signal levels to be protected and also regarding protection ratios often differ from the latest recommendations of the ITU. In North America the 0,5 MHz to 1,7 MHz band is regulated by the North American Regional Broadcasting Agreement (NARBA). It should be noted here that some of the differences result from differences in broadcasting philosophies. In Europe, for example, it is usual to have a few omnidirectional transmitters of high power to cover an entire country. In North America, on the other hand, there is a multitude of individual stations, often with highly-directional aerial arrays aiming a signal at a particular city or region of the country. Transmitter power is usually limited to 50 kW and protected received signal levels are generally lower than those specified in Europe.

NOTE The upper and lower limits of the various frequency bands, used for broadcasting and given here, are approximate values. Exact values vary from one region to another and are subject to periodic revisions. (See [62][3] for more details.)

3.2.3 *Minimum broadcast signal levels to be protected*

Individual national authorities should determine the minimum signal levels to be protected from power-line noise related to appropriate weather conditions. For the low-frequency and medium-frequency bands, the ITU [63] has recommended minimum field strengths necessary to overcome natural noise (atmospheric noise, cosmic noise, etc.). For broadcast planning purposes, the ITU has also recommended, for information only, nominal usable field strengths. Appendix C gives recommended values for both the minimum and the nominal usable field strength.

Since natural noise levels vary with time and geographical location, signal levels below these values can sometimes be received satisfactorily and at other times unsatisfactorily, irrespective of power line or other man-made noise.

[3] The figures in square brackets refer to "Bibliography and references" of CISPR 18-1 (1982) and CISPR 18-2 (1986).

The minimum levels recommended by the International Radio Consultative Committee (CCIR) for the v.h.f. bands for Region 1 are as follows:

Frequency band	Minimum signal strength
Television band I, 47 MHz to 68 MHz	48 dB (1 µV/m)
F.M. radio band II, 87 MHz to 108 MHz	48 dB (1 µV/m) (for mono) 54 dB (1 µV/m) (for stereo)
Television band III, 174 MHz to 230 MHz	55 dB (1 µV/m)

In North America, signal levels at the edge of the service area of a broadcasting station are specified by NARBA and other standards [64 to 66]. These levels are given in Appendix D.

It is generally accepted that when criteria for the protection of TV in bands I and III have been fixed, f.m. monoaural radio is automatically protected. The protection requirements for f.m. stereo radio are under consideration. Similarly, the intermediate bands, such as short wave, will automatically be protected by the medium-wave broadcast band protection. However, in certain cases, there may be telecommunication services requiring different protections. These should be taken into account by national authorities when limits are being considered.

It should be borne in mind that all of these minimum signal levels are related to protection against interference from other radio signals or from natural noise. Interference from power line noise has not been considered.

With the widely differing values adopted for usable signal levels for different zones of the world, daytime and night time, the term “reasonable signal level” has to be established with regard to the factors relevant to the different levels. It is inevitable that if low levels are adopted, radio noise from power lines should be viewed in comparison with other sources of interference, and the protected distance between the power line and receiver should be increased and/or the acceptable signal-to-noise ratio reduced.

3.2.4 *Required signal-to-noise ratio*

3.2.4.1 *Radio broadcasting*

No exact recommendations regarding the acceptable signal-to-noise ratios have yet been devised for noise from power lines. For planning purposes, the ITU recommends a wanted-to-interfering signal ratio of 30 dB. NARBA levels are based on a ratio of 26 dB.

For similar ratios, power-line noise may represent somewhat less objectionable interference than does co-channel interference.

As for a.c. lines, the technical literature [19, 20, 55, 68 and 69] contains results of investigations of required signal-to-noise ratios for satisfactory reception in the presence of d.c. power-line noise. However, the number of investigations is much less for d.c. lines than for a.c. lines, and the d.c. signal-to-noise ratio tests are not as consistent with each other as are the a.c. signal-to-noise ratio tests. Some of the investigations have shown that in the case of d.c. lines the measured signal-to-noise ratios could be as much as 9 dB lower than for a.c. lines to give the same subjective impression, whereas other investigations have seen little difference between a.c. and d.c. lines. Until these discrepancies can be resolved by further research, it is recommended that a.c. signal-to-noise ratio data be used by National Regulatory Authorities in developing limits for d.c. lines.

3.2.4.2 *Television broadcasting*

The required signal-to-noise ratios for television reception are less definite than those for radio. For the European television standards, 40 dB appears to be generally acceptable (the bandwidth of the CISPR meter being 120 kHz). However, tests carried out in the United Kingdom with a positive modulated black and white picture showed that this value could be reduced by up to about 5 dB. For the North American television standards, several limited tests have suggested 40 dB for black and white television [58]. Tests on colour television are currently being carried out. Further consideration of all these issues is required.

The repetition rates of noise pulses due to corona and to gap-type discharges may differ considerably. This may have a large influence on the degree of interference produced on a television picture. Although there is not much data available, this should be considered when establishing acceptable signal-to-noise ratios for television reception.

3.2.5 ***Conversion of measured values***

3.2.5.1 *Attenuation laws*

The rate of lateral attenuation of radio noise, for distances between about 20 m and 100 m from the nearest positive conductor of a line, varies in different frequency ranges and also depends on the configuration of the line. The following approximate values should provide satisfactory results:

— 0,15 MHz to 0,4 MHz, noise level decreases as $D^{-1,8}$

— 0,4 MHz to 1,7 MHz, noise level decreases as $D^{-1,65}$

— 30 MHz to 100 MHz, noise level decreases as $D^{-1,2}$

— 100 MHz to 300 MHz, noise level decreases as $D^{-1,0}$

Presumably the factor 1,65 is somewhat valid between 1,7 MHz and 30 MHz. The information for the 30 MHz to 300 MHz band is based on a few measurements, but it must be appreciated that the mechanism and also the attenuation law are dependent on the type of noise source, for example conductor corona or gap-type discharges at fittings.

The noise levels referred to 20 m from the nearest conductor of a line may, therefore, be corrected to the protected distance, using the following correction formulae:

0,15 MHz to 0,4 MHz $$E_p = E_o - 36 \lg \frac{D_p}{20}$$

0,4 MHz to 1,7 MHz $$E_p = E_o - 33 \lg \frac{D_p}{20}$$

where

E_p is the radio noise level at protected distance, dB (1 μV/m);

E_o is the radio noise level at 20 m, dB (1 μV/m);

D_p is the protected distance (m).

NOTE Numerous measurements in the medium frequency band have demonstrated that, on average, the noise level decreases as $D^{-1,65}$ close to the line (see **4.2** of CISPR 18-1). For greater distances, however, some measurements have shown that it decreases as D^{-1}. For any distance greater than about 100 m, a more accurate value for the noise level E_p may be given by:

0,4 MHz to 1,7 MHz

$$E_p = E_o - 23 - 20 \lg \frac{D_p}{100} \qquad D_p > 100 \text{ m}$$

There is a degree of uncertainty as to the lateral distance beyond which this formula applies. In most cases, however, at distances beyond 100 m the noise level will be so low that broadcast reception will not be affected.

3.2.5.2 *Distance of measurement*

Whenever possible, measurements should be made at a distance of 20 m from the positive pole. When this is not possible, the above formulae may be used to convert measured values taken at other distances to the standard CISPR distance of 20 m. Measurements should also be taken at distances other than 20 m for verification purposes. In all cases, measured profiles of lateral attenuation are greatly preferable to the use of correction formulae (see also **1.2.3**).

3.3 Methods of determining compliance with limits

The approximate radio noise field due to conductor corona may be predicted for a power line by use of the following empirical formula (see **8.2** of CISPR 18-1) in fair-weather and at 0,5 MHz.

$$E = 38 + 1,6\,(g_{max} - 24) + 46 \lg r + 5 \lg n + 33 \lg \frac{20}{D}$$

in dB (1 μV/m)

where

E is the radio noise field;

g_{max} is the maximum surface gradient of the line, in kilovolts per centimetre;

r is the radius of conductor or subconductor, in centimetres;

n is the number of subconductors;

D is the distance between aerial and nearest conductor, in metres.

At frequencies different from 0,5 MHz, especially if a signal at a specified broadcast frequency is to be protected, the calculated radio noise level should be corrected according to the following formula (see also **4.2.1** and Figure B12 of CISPR 18-1):

$$\Delta E \text{ (dB)} = 5\,[1 - 2\,(\lg 10\,f)^2]$$

where ΔE (dB) is the variation of the radio noise level from the reference frequency of 0,5 MHz and f is the frequency expressed in megahertz over the range 0,15 MHz to 4 MHz. This correction is basically derived from a.c. lines and is applicable to d.c lines until further experience is achieved.

It should be noted that the prediction formula for the radio noise level given above represents the 50 % fair-weather value. In order to achieve the 80 % all-weather value, another 3 dB to 4 dB should be added to the formula.

Reliable prediction of noise levels is important, as no corrections of line design or construction can economically be made after the line has been built. Once the line is in service, there are several alternative measurement procedures by which this predicted level may be verified. The choice of method will depend on the time available for the measurements and on the degree of accuracy required.

3.3.1 *Long-term recording*

This is the most precise method for evaluating the noise level produced by a power line but it takes a long time to obtain the results. A noise-recording station is set up close to the power line under investigation and continuous measurements are made for at least one year. The suitability of the recording site must be checked by means of measurements at various points along the line. The results are plotted on a probability graph of the type shown in Figure 3 of CISPR 18-1. At the percentage of time that has been selected for specifying the noise, the level is read from the graph.

3.3.2 *Sampling method*

This is a practical and accurate method that follows the spirit of CISPR Recommendation 46/1. At least 15 or preferably 20 or more individual sets of measurements of noise level are carried out at various locations along the line and under various weather conditions. The selection of different weather conditions should be more or less in proportion to the percentage of time each weather condition exists in the area of the power line. These measurements are then analysed to give the noise level that will not be exceeded for 50 %, 80 % or 95 % of the time, with an 80 % confidence, according to the chosen criterion (see **2.3.1**). The sampling method is fully described in 1.4 in the case where the chosen criterion is the 80 % level.

3.3.3 *Survey methods*

If time or any other reason does not allow either of the above methods to be used, the alternative of making measurements in fair-weather may be considered. This can be adequate when conductor corona is the main noise source and when the radio noise distribution curves for the particular type of line for the all-year-round weather conditions are available. These curves could, for instance, have been obtained from previous accurate measurements on the actual or on the same type of line under similar climatic conditions. Preferably three distribution curves should be available: under fair-weather conditions, under heavy rain, and under all-year-round weather conditions. Statistical distributions are discussed in **4.2.3** of CISPR 18-1.

Fair-weather measurements have to be made at various locations along the line and at different times. From the results, the 50 % fair-weather level is deduced and used as a reference in the set of curves mentioned above. From the curves the all-weather 80 % value can then be assessed. The success of this method is dependent on the reliability of the distribution curves. In general the 80 % all-weather value is about 3 dB higher than the 50 % fair-weather value.

3.3.4 ***Alternative criteria for acceptable noise level***

One of the alternative criteria for acceptable noise levels, as discussed in **2.2**, may be used. If, for example, the average fair-weather noise level is chosen, then a series of measurements should be carried out during typical fair-weather conditions. At least three measurements should be carried out at three different locations along the line. If time permits, this should be repeated on another day. The average of all the measurement values will be considered to represent the average fair-weather noise level of the line.

3.4 Examples for derivation of limits

3.4.1 ***Radio reception***

Examples of the calculation of limits are given below based on the assumptions discussed in the preceding subclauses. Limits could also be calculated for different assumptions in respect of signal level, signal-to-noise ratio and distance from a power line. Conversely, for a given level of noise, the minimum acceptable distance for satisfactory reception of a given signal strength, could be calculated.

It should be borne in mind that the lateral attenuation laws quoted are average values. They depend on factors relating to both line design and local conditions. They may change with distance and should not be used for distances materially beyond those assumed in this subclause.

3.4.1.1 *Principle*

There are four parameters involved in the specification of radio noise limits (see Figure 11):

— the minimum signal level to be protected;

— the minimum acceptable signal-to-noise ratio;

— the reference noise level, 20 m from the nearest conductor, during prescribed weather conditions;

— the "protected distance", that is, the minimum distance from the line at which the signal can be satisfactorily received.

If any three of these parameters are specified, the fourth can be determined. Two examples will demonstrate this.

3.4.1.2 *Example 1*

If the value of the noise level at 20 m from the nearest conductor, the protected signal level and the required signal-to-noise ratio are all known, the protected distance D_p (in meters) from the power line for satisfactory radio reception in the low and medium frequency bands may be calculated from the following formula, given in Appendix F of CISPR 18-2.

$$D_p = 10^{\left(\frac{E_o - E_p}{K} + 1,3\right)}$$

where

E_o is the noise level at 20 m from the nearest conductor, in dB(1 µV/m);

$E_p = S_p - R_p$ is the acceptable noise level at D_p, in dB(1 µV/m);

R_p is the required signal-to-noise ratio, in decibels;

S_p is the protected signal level, in dB(1 µV/m).

E_p depends on E_o and D_p according to the attenuation formula given in **3.2.5.1**: $E_p = E_o - K \lg (D_p/20)$ where K = 36 and 33 for l.f. and for m.f. bands respectively.

In the m.f. band, the formula for the protected distance D_p is accurate for distances up to about 100 m.

As an example, the distance from a given power line at which a signal of 72 dB (1μV/m) at 1 MHz may be received with a signal-to-noise ratio of 35 dB is required. The line noise measured by the standard CISPR method is found to be 50 dB (1 μV/m). The following calculation is made:

Protected signal level at 1 MHz	S_p = 72 dB (1 μV/m)
Required signal-to-noise ratio	R_p = 35 dB
Acceptable noise level at protected distance from line	N_p = Sp – R_p = 37 dB (1 μV/m)
Measured noise level at 20 m from nearest conductor at 0,5 MHz	50 dB (1 μV/m)
Noise level at 1 MHz	E_o = 50 – 6 = 44 dB (1 μV/m)
(The 6 dB correction comes from Figure B12 of CISPR 18-1)	
Protected distance	$D_p = 10^{\left(\frac{44+35-72}{33}+1,3\right)}$

Therefore: D_p = 32 m from nearest conductor.

3.4.1.3 *Example 2*

In this second example a broadcast signal at 1 MHz, 65 dB (1 μV/m), is to be protected with a signal-to-noise ratio of 30 dB at distances greater than 100 m from the power line.

The acceptable reference noise level at 20 m is calculated as follows:

Protected signal level at 1 MHz	65 dB (1 μV/m)
Acceptable noise level at protected distance from line	65 – 30 = 35 dB (1 μV/m)
Attenuation from 20 m to 100 m	$33 \lg \frac{100}{20} = 23$ dB
Acceptable reference noise level at 20 m from nearest conductor, at 1 MHz	35 + 23 = 58 dB (1 μV/m)
Therefore: acceptable reference noise level at CISPR reference frequency (0,5 MHz) (The 6 dB correction comes from Figure B12 of CISPR Publication 18-1.)	58 + 6 = 64 dB (1 μV/m)

3.4.2 *Television reception, 47 MHz to 230 MHz*

This is under consideration. Insufficient information is presently available to permit presentation of meaningful examples.

3.5 Additional remarks

Most field tests to date have been carried out in the low and medium frequency bands. Therefore, any data presented on the v.h.f. band should be considered as provisional and major conclusions should not be based on it. This whole subject is still under consideration.

If limits are based on noise levels measured and statistically evaluated in accordance with **1.4**, they also represent statistical values not exceeded for 80 % of the time. For conductor corona noise it should be noted that these values are about 3 dB higher than average fair-weather levels. This factor should be taken into account when these values are compared with standards for typical fair-weather conditions laid down in various countries.

As in the case of other sources of possible interference for which CISPR limits exist, examples of limits presented here are based on the requirements for the protection of reception for the large majority of listeners or viewers under conditions prevailing at the majority of sites during most of the time. Such values cannot cater for the few exceptional cases where a number of unfavourable factors coincide.

Practice has shown that acceptable noise levels in this subclause can be met with well-maintained power lines of adequate design and construction. Indeed, considerably lower levels are found on many operational lines where requirements other than radio noise lead to designs with larger conductor sizes (for example high current-carrying capacity). It is considered that the methods of deriving limits indicated in this subclause represent good engineering practice and could serve as the basis for establishing such limits.

4 Procedures for determining limits of radio noise produced by Insulator sets

4.1 General considerations

CISPR publication 18-2 (1986) gives general procedures for setting up limits of the radio noise produced by overhead lines and substations. In clause **2.7** technical considerations are given, with reference to low and medium frequency broadcast bands, for the coordination of the radio noise produced by the insulator sets with that produced by the conductors.

The general principle for this coordination is to design the insulator sets in such a way that their noise contribution to the overall noise of the line or of the substation is negligible for any surface condition of the insulators. In this respect, a difference of 10 dB between the radio noise current produced by one span of one phase conductor and that of one insulator assembly is considered as being adequate. In addition, following this principle, the noise current injected into the outgoing lines by the insulator assemblies of a substation, should not increase the intrinsic noise of these lines. To limit any increase to a maximum value of 3 dB, the radio noise current produced by each insulator assembly within the substation should not exceed the value $I_0 = I\, n/\sqrt{N}$ where I is the line conductor noise current at the substation side, n the number of outgoing lines and N the number of insulator sets in the substation.

The above principle is economically justified when the noise level produced by the conductors is close to the maximum admissible level (e.g. gradients greater than 12 kVrms/cm to 14 kVrms/cm). For lower conductor noise this principle could be uneconomic and it could be acceptable that the radio noise produced by the insulator sets prevails in respect to the noise produced by the conductors. In this case the limit for the radio noise current of each insulator assembly is directly obtained from the maximum admissible overall level of the line.

According to CISPR 18-2 and IEC 437, the verification of the radio noise level of the insulator assembly is at present made with reference to only a standard and reproducible condition of the insulators (clean and dry).

Since the influence of ambient and weather conditions is not the same for conductors and insulators, radio noise limits for insulators established considering only the clean and dry condition may not guarantee acceptable values for other conditions.

This clause intends to give, on the basis of the results of systematic radio noise tests in different countries on various types of insulators, guidance to take into account the effect of the insulator surface conditions in the selection of the radio noise limits of insulator sets. The limits and test procedures suggested are applicable to the cases of insulators to be installed in areas where they will remain clean or slightly polluted. For insulators in polluted conditions, with high humidity and formation of sparks across dry bands, only some indications about possible remedies are indicated.

4.2 Insulator types

The criteria given in this publication are mainly applicable to cap-and-pin type insulators, for which more complete information on the influence of surface conditions on the radio noise performance of insulators is available. For long-rod insulators only a little data can be found in the literature. However, it can be assumed that for this type of insulator the radio noise problem is generally of little concern in clean and slightly polluted conditions; for heavy pollution the conclusions that will be drawn for cap-and-pin insulators can be generally applied to long rod insulators.

In addition, regarding cap-and-pin insulators, for practical reasons the majority of the available data refers to single insulator units. However, as regards dry conditions, the difference between the radio noise voltage levels of polluted and clean insulators obtained on single units is directly applicable also to insulator sets, since the voltage distribution along the string is being determined by the string capacitances and therefore are not affected by dry pollution, in wet conditions, both for clean and polluted insulators, the differences of radio noise voltage levels in comparison with the dry conditions are generally lower for the strings than for the insulator units considering the better voltage distribution in wet conditions: conclusions on the above differences for insulator units are therefore on the safe side when applied to the insulator sets.

4.3 Influence of insulator surface conditions

The analysis of the radio noise behaviour of the insulators in respect of the surface conditions is made with reference to the following classification:

— *clean insulators:* it is an ideal condition in which the insulators remain completely clean, close to the situation of the present laboratory test according to CISPR 18-2 and IEC 437;

— *slightly polluted insulators:* no important dry-bands are present in wet conditions; it is the most common situation in relatively clean areas after a certain period of service;

— *polluted insulators:* dry bands are present in wet conditions; it is the situation in service in polluted areas of various pollution severities.

The analysis of the data confirms that it is very difficult to give general conclusions on the effects of surface conditions, due to the great dispersion of the results, especially when the insulators are slightly polluted, and due to the different behaviour of the different types of insulators.

Even with these limitations, it is possible to give some qualitative trends and average quantitative estimations.

The following general considerations apply both to glass and to porcelain cap and pin insulators.

4.3.1 *Clean insulators*

The radio noise level of insulators decreases with the increase of the relative air humidity for all types of insulators. Figure 13 gives an example of typical trends for individual cap-and-pin insulator units; for insulator strings the influence is more pronounced, considering the favourable effect of the humidity, which linearizes the voltage distribution along the string, In any case, the reduction of the radio noise level with an increase of the humidity is much higher for the insulators than for the conductors, for which this reduction is negligible.

In the presence of condensation without water drops, due to light fog or dew, the radio noise behaviour of a clean insulator is similar to that of the same insulator at very high humidity (90 % – 95 %).

The radio noise level of insulators increases in the presence of water drops on the insulator surface (due to rain, thick fog or dew, snow, ice). However, this increase is generally lower than in the case of conductors (10 dB – 12 dB compared to 18 dB – 22 dB).

The radio noise frequency spectrum of clean insulators is similar to that of the conductor.

4.3.2 *Slightly polluted insulators*

Under slightly polluted conditions, the majority of insulator types show a radio noise behaviour, as a function of the relative air humidity, similar to that of the same insulators in clean conditions. However, some types of insulators with particular characteristics, such as high mechanical performances or especially designed for very low radio noise in clean and dry conditions, may present a different behaviour. As regards in particular the insulators with very low radio noise levels in clean conditions, a great increase of the radio noise level at relative air humidity greater than 50 % – 60 % was found for some of them, as shown by Figure 13.

In the presence of condensation without water drops on the insulators, due to light fog or dew, the radio noise behaviour of a slightly polluted insulator is similar to that of the same insulator at very high humidities (90 % – 95 %).

In the presence of water drops (due to rain, thick fog or dew, snow, ice) the radio noise behaviour of a slightly polluted insulator does not appreciably differ from that of a clean insulator.

As in the case of clean insulators, the radio noise frequency spectrum of slightly polluted insulators is similar to that of the conductor.

4.3.3 *Polluted insulators*

For relative air humidity lower than 60 % – 75 %, the radio noise behaviour of polluted insulators is similar to that of clean and slightly polluted insulators.

For higher humidities or in case of condensation (light fog or dew), the predischarge phenomenon across dry bands produces very high noise levels; these levels are not related to those found in clean or slightly polluted conditions; they can only be controlled by drastically reducing the voltage stress (increase in an unrealistic manner of the insulator string length or of the leakage path in respect of that imposed by insulation requirements). Other special remedies, corresponding to limiting the pulses of the leakage current, are the use of special insulators (composite insulators, semiconducting-glazed insulators), greasing or washing of insulators.

In the presence of water drops on the insulators (rain, thick fog and dew) the critical situation is at the beginning, when the insulator is still heavily polluted: here the predominant phenomenon is predischarge across the dry bands. After a certain time, depending on the intensity of the rain, fog, or dew and on the shape of the insulator, the radio noise behaviour tends to that of slightly polluted and clean insulators in presence of water drops.

The frequency spectrum of wet polluted insulators with predischarges across the dry bands extends to higher frequencies (up to few tens of megaherz) than in the other cases: medium frequency and television reception can be disturbed.

4.4 Criteria for setting up radio noise limits for insulators

On the basis of the considerations of the previous clauses the criteria for setting up limits and testing the insulators shall be established with reference to the different areas in which the insulators are to be installed. These areas are:

Type A areas:	areas where the insulators remain clean: they are generally characterized by the absence of contaminating phenomena and frequent natural insulator washing due to rain or high and frequent dew condensation;
Type B areas:	areas where the insulators become sligtly polluted: they are generally characterized by low-intensity contaminating phenomena and by cleaning agents such as rain or heavy dew condensation that limit the contaminant accumulation on the insulator surface so that the formation of partial discharges across dry bands appears very seldom;
Type C areas:	areas in which the insulators become polluted so that the formation of partial discharges across dry bands is frequent.

4.4.1 ***Criterion for insulators to be installed in type A areas***

For these areas the present radio noise test on clean and dry insulators is sufficient. The coordination criteria and the margin M of 10 dB indicated in clause **4.1** guarantee an acceptable radio noise performance of the insulator sets in any atmospheric conditions. Considering the great influence of the relative humidity, the test should be performed in a limited range of humidity (e.g. 50 % – 70 %).

4.4.2 ***Criterion for insulators to be installed in type B areas***

For these areas the present test on clean and dry insulators, associated with the coordination criteria and margins indicated in **4.1**, is not sufficient to guarantee in all cases an acceptable radio noise performance of the insulator sets in any atmospheric conditions: in fact, as reported in **4.3**, in the case of very high humidity or condensation, a great increase of the radio noise level may be found for a few particular types of insulators.

To take account of this fact, it is recommended to maintain the test on clean and dry insulators which has been defined (see CISPR 18-2 and IEC 437), easy to perform and well reproducible, but to adopt a greater safety margin than in the case of insulators to be installed in type A areas.

This procedure could be too conservative for many insulators. For this reason, the choice of the most appropriate additional safety margin should be made on a statistical basis taking into account the reciprocal radio noise behaviour of conductor and insulator in the various surface and ambient conditions and the frequency of occurrence of each condition for the line under consideration. As a guidance, considering the most common types of insulators and with reference to an average moderate climate, an additional safety margin M of 8 dB (18 dB in total) should be adequate for high-voltage lines and substations.

NOTE The possibility of introducing an alternative procedure, consisting of a test on slightly polluted insulators at high humidity (75 % – 90 %) was also considered. It is not recommended because it requires a new test procedure to be set up, which is difficult and expensive. It is, in fact, difficult to obtain in the laboratory a reproducible pollution layer duplicating the natural light pollution taking into account the fact that the radio noise level depends on the distribution of the pollution deposit; in addition, it would be necessary to perform the test in a climatic room, in order to maintain the relative humidity in the required range. Some attempts have been made to perform the test on insulators artificially polluted with a slurry which maintains its humidification during the test: for light pollutant layers, this procedure is, however, quite complex and requires very sophisticated methods of pollution application. For these reasons, tests on slightly polluted insulators can only be considered for research purposes.

4.4.3 *Insulators to be installed in type C areas*

For these areas, the present radio noise test on clean and dry insulators does not give any indications of the radio noise behaviour of the insulators in wet and polluted conditions. For these conditions, a specific test on artificially heavily polluted insulators should be considered. It is, however, difficult to control the radio noise level of wet polluted insulators, which depends on the design of the insulators, the type of deposit and the non-uniform distribution of the pollution deposit on the insulator surface and along the string.

In **4.3.3** possible remedies have been indicated, which may involve drastic reduction of the voltage stress, use of special insulators, greasing or washing.

4.5 Recommendations

In the light of present experience it is possible to give the following recommendations (Table 1) for test methods and radio noise limits to be applied to insulator sets to be installed in the different areas defined in **4.4**.

It is worth remembering that the recommended procedure consists in tests on clean and dry insulator sets, both for insulators to be used in areas where they will remain clean (type A areas), and for those to be used in areas where they will become slightly polluted (type B areas). The only difference is that lower limits of the radio noise voltage are required for insulators to be installed in type B areas.

For the evaluation of these limits the margins M indicated in **4.4** between the total electric field E_c produced by the conductors and the total field E_i produced by the insulator sets of the line are applied ($M = 10$ dB and $M = 18$ dB for insulators to be used in type A and type B areas respectively). The relationship between the total field E_i produced by all the insulator sets and the radio noise current I_s produced by a single insulator set is given by the following simplified formula (formula 6 of CISPR 18-1, **6.2.1**):

$$E_i = I_s + A + [D - 10 \lg (s/500)] + C$$

where:

A takes into account the splitting of the injected current I on either sides of the injecting point (in the most common case, for a relatively long line, A = – 6 dB);

[D – 10 lg (s/500)] takes into account the aggregation of the noise sources along the line for span length s in meters, at a length of 500 m (average values of D lie between 10 dB and 12 dB);

C is the field factor that gives the correlation between the noise field and the noise current (at a distance of 20 m from the line and for an average line configuration. C lies between 7 dB and 12 dB);

E_i is given in dB (μV/m) and I_s in dB (μA).

As an example, considering the average values given above for the parameters of the formula, and a span length of 500 m

$$I_s = E_i - 17$$

Since it is used to express the radio noise current I_s, produced by a single insulator set in terms of radio noise voltage V (dB/1 μV/300 Ω) produced across a resistance of 300 Ω (see CISPR 18-2),

$$V = I_s + 20 \lg(300) = E_i + 33 = E_c - M + 33$$

This relationship originates the radio noise voltage limits indicated in the following Table 1.

Table 1 — Recommendations for the radio noise voltage limits and for the test methods for insulator sets installed in different areas

Type of area where the insulator will be installed (clause 4)	Radio noise voltage limits (db/1µV/300 Ω)	Test methods
A	E_c + 23	According to CISPR 18-2 and IEC 437 (on clean and dry insulators)
B	E_c + 15	
C	Indications for limits and test procedures applicable to insulators to be installed in type C areas cannot be given at present. Possible remedies, in the case of non-acceptable radio noise levels, are: the reduction of the voltage stress by means of longer insulator strings, or leakage paths; the use of composite insulators; the greasing or periodic washing of the insulator sets.	
E_c = 50 % fair-weather radio noise voltage level produced by the conductor at 20 m from the outer phase of the line (dB/1 µV/m).		

NOTE 1 The limits reported in Table 1 are applicable to lines characterized by conductor noise level close to the maximum admissible level (voltage gradients higher than 12 kV/cm – 14 kV/cm).

For lines of special design (having particularly low conductor noise), the direct application of the limits indicated in Table 1 could lead to uneconomical requirements for the insulators; to avoid this, the formula of Table 1 could be utilized also per these lines provided that if E_c is intended not as the conductor noise of the line under consideration, but the one produced by the conductors of a line of the same category (voltage level, tower geometry, region, etc.) with normal conductor design.

NOTE 2 The values in Table 1 apply to line insulators; similar approaches can be applied to substation insulators in respect to the noise in the substation itself and the noise conducted into the outgoing lines.

5 Methods for derivation of limits for the radio noise due to HVDC converter stations and similar installations

5.1 General considerations

There are principally two different sources of radio noise generation in HVDC converter stations and similar high-voltage installations, such as static var compensators (SVCs), incorporating thyristors in their operation. First, corona discharges on conductors, insulators, and hardware cause noise, similar to that in a.c. systems. This corona noise can be easily held to acceptable levels by proper electrical design of the busbars and hardware in the station. Second, the converter or control valves cause interference due to the rapid breakdown of the voltage between anode and cathode during valve firing. This noise, unlike noise due to corona, is independent of weather but is influenced by the characteristics of the converter equipment and by the valve operating conditions.

Without any suppression measures, the radio noise level from the converter or the control valves could be intolerable and it is, therefore, necessary to reduce this level to an acceptable value with appropriate methods like those indicated in **5.3.3** and **5.4.3**.

An evaluation of the radio noise radiated, directly by a converter valve can be performed by means of the analytical methods of calculation proposed in the literature [75], [76], [77], [78]. Reference [75] also gives methods of calculating the high frequency oscillations in the station using simplified equivalent circuits.

The disturbance levels shown in Figure 15 to Figure 22 are not to be considered as typical reference values. They are simply given as examples of the influence of the different parameters considered (distance from the station, technology of the valves, etc.) on the levels of disturbance.

5.2 Sources of interference

5.2.1 *Mechanism of radio noise generation*

An HVDC converter station is generally made up of several converter groups. Each one of these groups normally comprises six valves (thyristor valves and also mercury arc valves in the past) fired cyclically at the power frequency. For obtaining higher voltages, several bridges may be connected in series per pole. The bridges are connected to the converter transformers on the a.c. side, and to the smoothing reactors on the d.c. side. A large amount of auxiliary equipment is also connected on both sides of the bridge circuits.

An SVC installation usually consists of a set of thyristor controlled reactors (TCRs) and thyristor switched capacitors (TSCs). The physical arrangement of the thyristor valves is similar to that of HVDC converter stations. The thyristors for the TCRs are switched over a range of firing angles to control the current to the reactors, while those for the TSCs are switched at a fixed point-on-wave (zero cross-over).

During the normal operation of such schemes, each valve is turned on and off once in every cycle of the alternating voltage. The valve firing thus occurs thus 6 times per cycle of the power frequency for a 6-pulse converter or SVC installation, and 12 times for a 12-pulse converter. The attenuation of the high-frequency currents generated by valve firing is so rapid that each pulse can, from a radio noise standpoint, be considered fully damped before additional pulses from other valves are injected in the system. For this reason, and due to the spread in the firing angles even if valves in different groups have the same transformer connections, the total level of the radio interference generated is not significantly different from that generated by a single valve.

The switching times during both turn-on and turn-off are very small, being usually of the order of a few microseconds. Thyristor valves, when fired, may have a voltage collapse time of up to 25 µs, compared with 1 µs for mercury arc valves. The reason for this is the use of damping circuits within the thyristor valve and the fact that the thyristor valve is composed of a number of thyristors connected in series. As a consequence the generated noise is in principle lower for thyristor than for mercury arc valves. Figure 14 shows the frequency spectra, recorded in the laboratory, of two transient phenomena of the same amplitude with rise times of 1 µs and 25 µS (average values for mercury arc and thyristor valves, respectively).

During both turn-on and turn-off of the valve, transient voltages and currents appear in the system as a result of the redistribution of the energy stored in the reactive elements before a new steady state is reached. During turn-off, most of the energy is stored in the inductance of the transformer windings. Thus, the transition to the new steady-state condition is achieved essentially at the relatively low natural frequencies of the transformer and the system. During turn-on, however, the energy to be redistributed is stored essentially in the various stray and lumped capacitances. This produces a rather complex system of oscillations whose spectrum depends not only on the amplitude and shape of the voltage collapse across the valve, but also on the layout of the connections and equipment connected. The noise spectrum extends in frequency up to a few megahertz.

This radio noise may be emitted directly from the valves and associated equipment comprising, in this instance, mainly the feeders and the busbars of the converter station. These busbars will often be of considerable length and well able to act as efficient radiators. The converter station will be, of course, connected to incoming and outgoing a.c. and d.c. circuits and these may consist of overhead lines. The radio noise will be guided and emitted from such overhead lines.

5.2.2 ***Influence of station design on radio interference***

As anticipated, the radio interference generated is influenced by the steepness of the valve firing voltage. For this reason, the radio noise generated by thyristor valves will be lower than that produced by mercury arc valves.

Besides the amplitude of the voltage collapse at the valve firing and the time of this collapse, the noise from the valves is primarily influenced by the height and capacitance to ground of individual valves. The radio interference has therefore a tendency to increase by the voltage and current rating of the valves as an increased rating means increased valve size. On the other hand, the noise is little influenced by the number of operating valves in a station. This has also been confirmed by measurements in operating converter stations.

The switchyard layout and the height and length of the busbars have also a great influence on the generated disturbance. A compact design of the switchyard will therefore have favourable effects on the radio noise generation. A practical solution consists of moving the converter transformers into the valve hall and using the transformer bushings as valve hall bushings. This solution lowers the radio interference significantly because the radiating loop between valves and transformers is small as it is entirely located inside the electromagnetically screened valve hall. Additional reduction of the radio interference from connecting lines could be achieved if the converter transformers were built with grounded electrostatic screens between the two windings.

Oil-cooled thyristor valves will require a metallic tank. In this case, the valve circuits will be effectively screened electromagnetically, and the radio interference problem will be significantly reduced.

5.3 Radiated fields from valve halls

5.3.1 *Frequency spectra*

Examples of frequency spectra due to direct radiation from a converter station are given in Figure 15 and Figure 16 for converter stations equipped with mercury arc and thyristor valves, respectively. No qualitative differences can be remarked between the radio noise spectra generated by mercury arc and thyristor valves converters.

5.3.2 *Lateral attenuation*

The interference from the valve hall is dominated by direct radiation from the converter valves and their connections to other pieces of equipment. The physical size of the radiating loops is small compared to the wavelength of the noise in the range of frequencies of interest (0,15 MHz to 30 MHz). Therefore, the converters can, from a radiation standpoint, be treated as vertical electrical dipoles (with a pure capacitive radiation impedance). As a first approximation, the analytical formulae derived from the antenna theory can be used to predict the lateral attenuation from the valve hall.

The attenuation of the noise level is approximately proportional to the inverse of the square of the distance for frequencies up to 1 MHz and becomes proportional to the inverse of the distance for higher frequencies (> 10 MHz).

The attenuation of the radio interference levels calculated as a function of the distance is given in Figure 17 for different frequencies.

5.3.3 *Reduction of the radio interference due to direct radiation from the valve hall*

The electromagnetic screen of the valve hall has proved to be effective for reducing the radiated noise from the converter valves. Solid metallic sheets, perforated sheets, and wire mesh may be used to achieve the desired shielding. However, due consideration should be given to the construction techniques, availability of materials, and overall cost before the design of the valve hall can be finalized.

Metallic screens having a high conductivity, and preferably also high permeability, in the form of either solid plates or wire mesh, are generally used in the walls and ceiling of the valve hall to provide the electromagnetic shielding. Together with the wire-mesh ground grid embedded in the floor, they form a Faraday cage around the valves. By taking appropriate precautions to ensure good contact between different sections forming this Faraday cage, the radiated interference can be attenuated by 40 dB to 60 dB. Any discontinuities, gaps or holes in the shielded enclosure will naturally reduce the attenuation.

The connections between the valves and the a.c. and d.c. sections of the outdoor switchyard provide a conductive coupling resulting in a radiation from the busbars and the various elements in the switchyard itself. This radiation may thus become much more important than that from the valve hall and thus the screening of the valve hall may not be sufficient to achieve the requirements on the radiated field from the converter station. In such a case also the radiated field from the switchyard shall be reduced. To do this at least two ways are possible. The first is to reduce the noise coming through the valve hall bushings by installing filters. Another is to screen the entire switchyard electromagnetically. If noise reduction within a narrow bandwidth is required, the first method is normally adopted. To make the filters more effective, they may be enclosed with the valve hall bushings in an electromagnetically screened building adjacent to the valve hall.

5.4 Conducted interference along the transmission lines

5.4.1 *Description of the mechanism and typical longitudinal profiles*

Radio interference currents are transmitted from the converter valves both to the d.c. and to the a.c. lines connected to the converter station. In the case of the a.c. lines, the high-frequency currents are conducted through the capacitive couplings of the converter transformer windings. A grounded shield between windings could be used to reduce this transfer.

The radio interference spectra due to currents injected by converter valves have a shape similar to those generated by corona. An example of noise spectrum, measured near the HVDC line at a short distance from a converter station is shown in Figure 18 and in Figure 19 for an a.c. line. Figure 20 gives the noise spectrum measured in the vicinity of the electrode line, at a distance of 1,5 km from the same converter station operated with thyristor valves and mercury valves.

The radio interference caused by the valve noise currents on the outgoing lines has been found to be dominated by the zero sequence component of the currents. The attenuation of this component is very high compared to that of line-to-line modes and therefore the radio noise level at a given distance from the line decreases rapidly with distance from the converter station. At higher distances, the line-to-line mode components will dominate. As a consequence, the radio interference due to the valves is overridden by corona noise at distances exceeding 5 km to 10 km from the converter station. For a.c. lines, the corresponding distance is somewhat longer. As a guide, an attenuation rate for the longitudinal profile of the radio noise equal to about 4 dB/km can be assumed [1], [42], [85].

Results of measurement of the frequency spectra along a d.c. transmission line at different distances from the converter station are given in Figure 21 and Figure 22. It has to be remembered that in the measurements performed in the vicinity of the first spans, the contribution of the direct radiation from the converter station cannot be disregarded.

For the evaluation of the lateral attenuation of the radio noise from the line, see **8.2** of CISPR 18-1.

5.4.2 *Reduction of the interference conducted along the transmission lines*

The electromagnetic disturbances due to valve firing, conducted and radiated from the d.c. and a.c. lines connected to a converter station may disturb not only the radio reception but also powerline carrier systems. For these telecommunication systems, especially in the frequency range from some tens to a few hundreds of kHz where the level of disturbance may be relatively high, filtering may be necessary.

Band-pass filters made of capacitors and inductors (generally with resistive dampers) shall take into account the stray capacitances and inductances of the bus connections and equipment. If filtering were necessary even in the frequency range above 1 MHz, simple filters made of a single conductor parallel to the line with a length equal to a quarter of the wavelength to be protected can be used. It has, however, to be noted that these filters allow for the protection of only a limited band of frequency.

5.5 General criteria for stating limits

In the case of HVDC converting stations, as for the radio interference from transformer stations, the assessment of general criteria for determining limits shall take into account the two propagation ways of the noise:

— direct radiation in the area around the converting station;

— propagation of the noise along the d.c. and a.c. lines starting from the converting station.

NOTE In limited areas close both to the converter station and to outgoing lines (these areas are within one or two kilometres at the most from the border of the converting station), there is a superposition of the two above ways of noise propagation. The effect of this superposition is difficult to be predicted. If it is deemed necessary to cover this aspect, an additional margin could be added to the limit for the radiated field.

5.5.1 *Direct radiation*

The radiated field at a reference distance from the border of the converting station should be limited according to the criteria indicated in clause **2** of this standard, which takes into account an acceptable signal-to-noise ratio and the statistical distribution of the noise level. To this purpose, it should be reminded that the radio noise produced by converter stations is not correlated, as corona noise, to the weather conditions. The reference 80 % value can be derived from a statistical distribution where the variability is determined by the different possible conditions of operation of the converter station (functioning as inverter or rectifier, firing and extinction angles, level of the direct voltage, etc.).

In practice, in the very frequent case of an HVDC converting station operating for more than 80 % of the time at conditions close to the nominal conditions, the 80 % radio noise level will coincide with that of nominal operating conditions.

5.5.2 *Propagation along the lines*

The basic criterion is that the contribution of the radio noise current due to the operation of the converting station in each line, d.c. and a.c., connected to the station, shall not substantially increase the intrinsic noise level of the line beyond a given distance from the station. This distance should be determined considering the type of area crossed by the line (rural areas, residential area, etc.). To keep this increase within 3 dB at the above-mentioned distance, the noise current arriving in that point from the converting station should be around 10 dB lower than the noise current of the line.

The noise current from the converter station at the distance of interest along the line, corresponds to the total noise current produced either on the a.c. side or on the d.c. side of the station divided by the number of a.c. and d.c. lines, respectively, diminished according to the expected longitudinal attenuation. Unless more specific information is available, the longitudinal attenuation factors indicated in **5.4.1** can be taken as a reference.

To determine the 80 % limits of the radio noise current generated by the converter station, the variability of the noise currents of the line (depending on weather conditions) and that of the converter station (depending on the operating conditions; see **5.5.1**) shall be taken into account. As the variability of the intrinsic noise of the line is generally much higher than that generated by the station, the limit for the station noise current can be determined conservatively comparing directly the 80 % values of the two distributions.

Appendix A Radio interference measuring apparatus differing from the C.I.S.P.R. basic standard instruments

In addition to the instruments specified in C.I.S.P.R. Publication 16, which are the basic reference instruments for determining compliance with C.I.S.P.R. limits in the frequency range 0.15 MHz to 300 MHz, there are instruments of other types used for radio noise measurements on power lines and high-voltage equipment.

In the United States and Canada, ANSI (American National Standards Institute) standard instruments which have quasi-peak detectors with a charge time constant of 1 ms and a discharge time constant of 600 ms have been generally used below 30 MHz. Above 30 MHz the C.I.S.P.R. and ANSI time constants are practically the same. At a given frequency below 30 MHz the ANSI meter usually reads 1 dB or 2 dB higher than the C.I.S.P.R. meter when measuring corona noise. New ANSI standards under consideration incorporate the C.I.S.P.R. specifications for the quasi-peak detectors.

Instruments with detectors other than quasi-peak which include r.m.s., average and peak detectors are specified in C.I.S.P.R. Publication 16. These instruments should be used for standard measurements only when conversion to quasi-peak values is possible. Although C.I.S.P.R. Publication 16 gives the conversions to quasi-peak values for periodically repeated pulses, these conversions do not apply to corona pulses which occur in bursts (see Sub-clause **1.1.1**).

Appendix B List of additional information to be included in the report on the results of measurements on operational lines

When the results of measurements are reported, the following additional information should be included:

a) Conductor surface voltage gradient — r.m.s. value for system voltage at time of measurements. State, in the case of bundles, if gradient is average or maximum.

b) Atmospheric conditions at measurement sites: temperature, pressure (altitude), humidity, wind speed, etc.

c) Pollution of conductors, insulators and fittings. State if "light", "moderate" or "severe" pollution and, if possible, the type of pollution, for example, cement or saline and the resistivity of the equivalent saline mist.

d) Type of insulator — if radio noise measurements, according to Sub-clause **1.3**, have been made on a complete insulator set of this type, the information should be included.

e) Conductor configuration including:

i) presence or not of earth conductor;

ii) number of conductors per phase and relative disposition;

iii) nature of conductor;

iv) height of conductors above ground at measurement site.

f) Age of line.

g) Line support — metal tower or wood or concrete pole.

h) Distance from nearest substation, transposition and angle structure and the presence or not of line traps for carrier communication equipment.

i) Distance from other lines or sources of interference which may affect the measurements.

j) Whether the results are from a single measurement or from a statistical assessment. Data from a statistical assessment may conveniently be presented in statistical form using cumulative probability paper. Results may be summarized by quoting the noise levels exceeded for 5 %, 20 %, 50 %, 80 % and 95 % of the time.

k) The period over which the measurements have been made. For a full assessment of the radio noise performance of a high voltage line, only measurements made over a sufficiently long period may be considered as significant.

l) Resistivity of the soil, if known.

m) The line loading (where this may be important).

Appendix C Minimum broadcast signal levels to be protected — ITU recommendations

For the l.f. and m.f. bands the ITU has established, for three climatic zones (A, B and C), the minimum field strength necessary to overcome natural noise (atmospheric noise, cosmic noise, etc.) [63]. These levels, which have been determined by adding 40 dB to the value of natural noise distribution exceeded for 10 % of the time, are given in Table CI:

Table CI — Minimum field strength

	Zone		
	A	**B**	**C**
Frequency (MHz)	**Field strength in dB** (1 μV/m)		
0.15	73	83	76
0.28	70.5	80.5	73.5
0.5	65	75	68
1.0	60	70	63
1.6	57	67	60

For broadcast planning purposes, the ITU has also recommended nominal usable field strengths. These recommendations, including the footnotes, are reproduced here for the 0.5 MHz to 1.7 MHz and 0.15 MHz to 0.28 MHz bands. The exact values of upper and lower limits of the various frequency bands, for different regions of the world, can be found in [62].

The nominal usable field strength values are shown in Table CII below in dB (1 μV/m).

Table CII — Nominal usable field strength

	Zone A	**Zone B**	**Zone C**
A. Medium frequency (0.5 MHz to 1.7 MHz)			
Daytime ground-wave service	63	73	66
Night ground-wave service[a]			
— rural areas[b]	71	81	74
— urban areas	77	87	80
Low-power channels	88	88	88
B. Low frequency (0.15 MHz to 0.28 MHz)[c]	77	87	80

[a] Where the transmitter power is sufficiently high for the ground-wave service area to be limited by fading due to the skywave of the same transmitter, a nominal usable field strength greater than the value given in the table may be chosen. It should not, however, be greater than the ground-wave field strength at the beginning of the fading zone. The fading zone may be defined by taking the protection ratio between the ground-wave and the sky-wave to be equal to the internal protection ratio applicable to a synchronized network, that is 8 dB.

[b] Some delegations consider a nominal usable field strength of 65 dB (1 μV/m) to be suitable for rural areas in their countries.

[c] Certain delegations consider a value of nominal usable field strength of the order of 73 dB (1 μV/m) to be appropriate in non-tropical rural areas.

Appendix D Minimum broadcast signals to be protected — North American standards

In North America, the signal levels at the edge of the service area of a broadcast station, according to NARBA and other standards [64], [65], [66] are:

Table DI — Signal levels at the edge of the service area in North America

Service	**Frequency** (MHz)	**Signal levels** [dB (1 μV/m)]
AM radio	0.5 to 1.7 Some "Class A" stations	54 40
V.H.F. television (Channel 2 to 6)	54 to 88	47
V.H.F. television (Channel 7 to 13)	174 to 216	56

Appendix E Required signal-to-noise ratios for satisfactory reception

A.M. radio broadcasting

Although no exact recommendations concerning acceptable signal-to-noise ratios have been devised for interference from power lines, a number of tests have been conducted throughout the world. These are summarized in reference [66]. In these tests, the noise was measured with either a C.I.S.P.R. meter or a meter satisfying ANSI Specification C63.2-1969. For measurement of the signal, some investigators used the quasi-peak detector and others used the average detector.

Table EI shows all the data, corrected to represent signals measured with an average detector and noise measured with the quasi-peak detector of a C.I.S.P.R. meter. Table EII defines the codes for quality of reception used in Table EI. Average rather than quasi-peak measurement of the signal level seems logical since signal levels, as defined by international bodies such as CCIR and NARBA, are average or r.m.s. values of the modulated signal.

For the development of limits, any of the ratios in Table EI could be used. It is not possible at present to state which is the most accurate. As a guide, the last column of Table EI shows the mean of all the values for each quality of reception.

Television broadcasting

Some signal-to-noise ratio tests have been conducted for power line noise in the v.h.f. television bands. The results indicate that a 40 dB ratio, with the signal measured by an average detector and the noise measured by a C.I.S.P.R. meter, with a quasi-peak detector, may be satisfactory. However, this subject is still under consideration.

Table EI — Summary of signal-to-noise ratios for corona from a.c. lines (Signal measured with average detector, noise measured with quasi-peak detector)

Canadian Voluntary Standard		**IEEE Radio Noise Design Guide**		**Lippert Pakala** *et al.*		**Taylor** *et al.*		**Gehrig** *et al.*		**Nigol**		**CIGRIÉ**		**Hirsch**		**De Michelis and Rosa**		**Mean**
Code	**Ratio** (dB)	**Code**	**Ratio** (dB)	**Code**	**Ratio** (dB)	**Code**	**Ratio** (dB)	**Code**	**Ratio** (dB)	**Code**	**Ratio** (dB)	**Code**	**Ratio** (dB)	**Code**	**Ratio** (dB)	**Code**	**Ratio** (dB)	
A1	39	—	—	—	—	0	41	—	—	—	—	—	—	—	—	—	—	40
A2	31	A5	31	A	31	1	35	—	31	5	—	5	30	1	30	0	36	32
B	26	B4	26	B	26	2	29	—	26	4	25	4	24	2	20	1	30	26
C	21	C3	21	C	21	3	23	—	21	3	21	3	18	3	14	2	24	20
D	15	D2	15	D	15	4	18	—	16	2	15	2	12	4	8	3	17	15
E	9	E1	4	E	7	5	12	—	10	1	—	1	6	5	—	4	10	8
—	—	F0	—	F	—	6	6	—	—	0	—	0	0	—	—	5	2	3

Table EII

The codes shown in Table EI, defining the quality of reception or degree of annoyance, as used by the various investigators are summarized below.

Canadian Voluntary Standard

A1 Entirely satisfactory for classical music
A2 Satisfactory for general listening
B Background noise reasonably unobtrusive
C Background noise evident
D Background noise very evident
E Difficult to understand.

IEEE Radio Noise Design Guide

A5 Entirely satisfactory
B4 Very good, background unobtrusive
C3 Fairly satisfactory, background plainly evident
D2 Background very evident, but speech easily understood
E1 Speech understandable only with severe concentration.

Lippert, Pakala, Bartlett, Fahrnkopf

0 Excellent
1 Entirely satisfactory
2 Very good
3 Fairly satisfactory
4 Speech easily understood
5 Speech understandable
6 Speech unintelligible.

Gehrig, Peterson, Clark, Rednour

Background not detectable
Background detectable
Background evident
Background objectionable
Difficult to understand
Unintelligible.

Nigol (Burrill's Code)

5 Entirely satisfactory
4 Very good, background unobtrusive
3 Good, background evident
2 Program easily understood, background very evident
1 Program badly distorted, background very evident
0 Program unintelligible.

CIGRÉ

5 Interference not audible
4 Interference just perceptible
3 Interference audible, but speech perfectly received
2 Unacceptable for music, but speech intelligible
1 Speech understandable only with severe concentration
0 Spoken word unintelligible; noise swamps speech totally.

Hirsch

1 Very good reception, no disturbance detectable
2 Good reception, disturbance without severe nuisance
3 Satisfactory reception, disturbance evident
4 Sufficient reception, distorted with very evident noise
5 Insufficient reception, program unintelligible.

De Michelis and Rosa

0 No interference. No disturbance perceived
1 Barely perceptible. Disturbance audible during conversation in a low voice, but not during conversation in a normal voice
2 Perceptible. Disturbance audible in any case but not particularly irritating
3 Somewhat objectionable. Disturbance audible even during musical broadcast
4 Definitely objectionable. Irritating but perfectly intelligible
5 Intolerable. Extremely irritating disturbance with reduced intelligibility.

Appendix F Derivation of formula for protected distance

The formula used in the examples in Sub-clause **2.5.1** is derived as follows:

The acceptable noise level at the protected distance is:

$$N_p = S_p - R_p$$

where:

N_p is the acceptable noise level at D_p, in dB (1 µV/m)

S_p is the protected signal level, in dB (1 µV/m)

R_p is the required signal-to-noise ratio, in decibels

D_p is the protected distance, in metres

But using the attenuation formula given in Sub-clause **2.3.5.1**:

$$N_p = E_0 - K \lg \frac{D_p}{20}$$

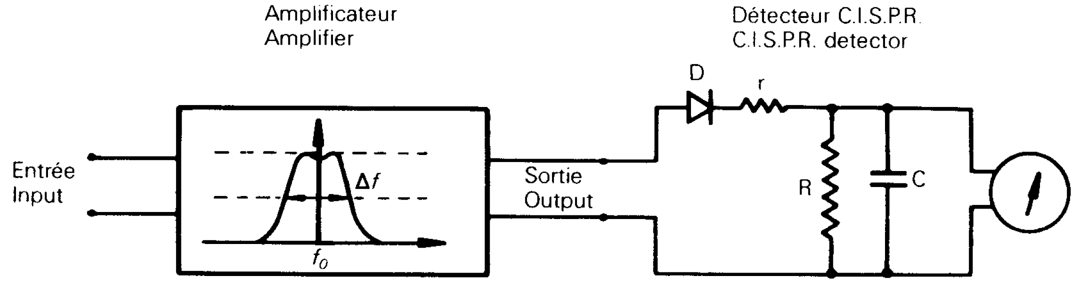
where:

E_0 is the noise level at 20 m from the nearest conductor, in dB (1 µV/m)

K = 36 for l.f. band
33 for m.f. band

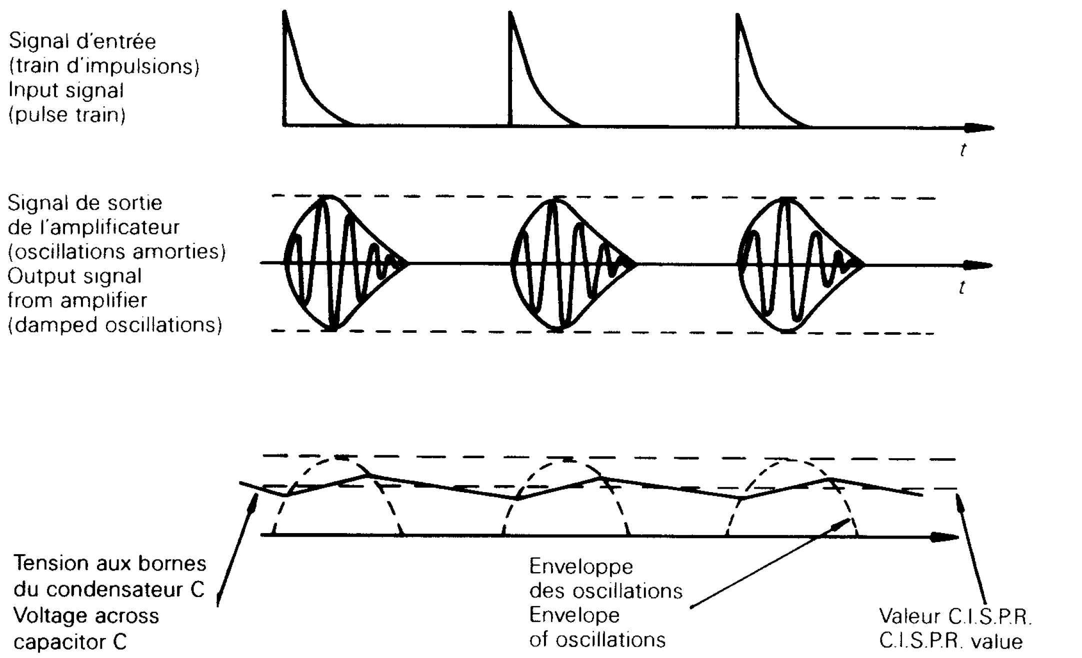
$$S_P - R_P = E_0 - K \lg \frac{D_P}{20}$$

Therefore: $D_p = 10^{\left(\frac{E_0 + R_p - S_p}{K} + 1.3\right)}$



Δf	=	**bande passante**
f_0	=	**fréquence centrale**
D	=	**diode**
r	=	**résistance de charge**
R	=	**résistance de décharge**
C	=	**condensateur**

Δf	=	**band width**
f_0	=	**centre frequency**
D	=	**diode**
r	=	**charging resistor**
R	=	**discharging resistor**
C	=	**capacitor**



CISPR 18-2/032/86

Figure 1 — Transformation of pulses through a C.I.S.P.R. measuring set

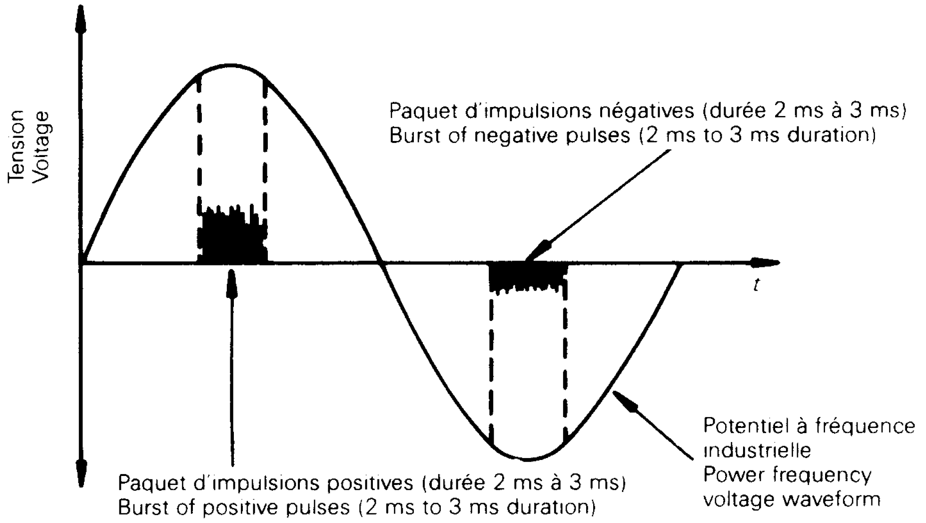


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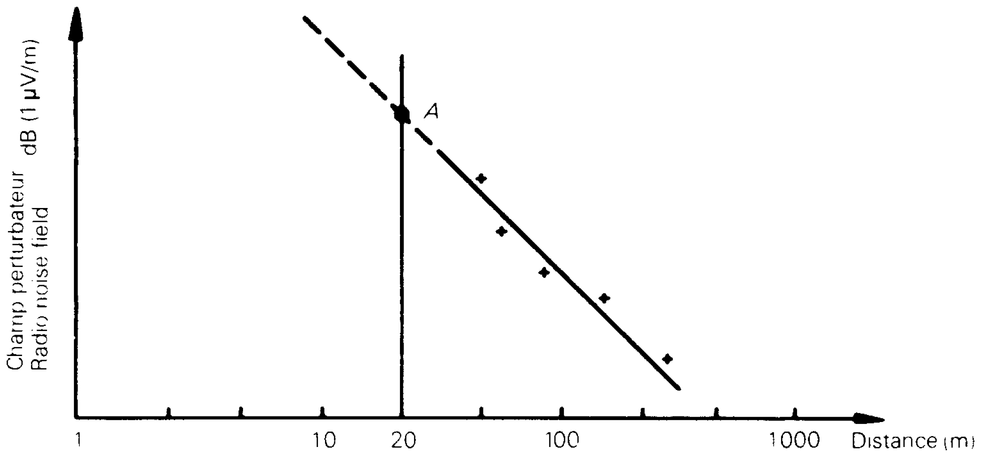
Figure 2 — Bursts of corona pulses generated by alternating voltage



CISPR 18-2/034/86

Niveau de référence
Reference level A

Niveaux mesurés
Measured levels ×

Figure 3 — Example of extrapolation to determine the radio noise field reference level of a power line

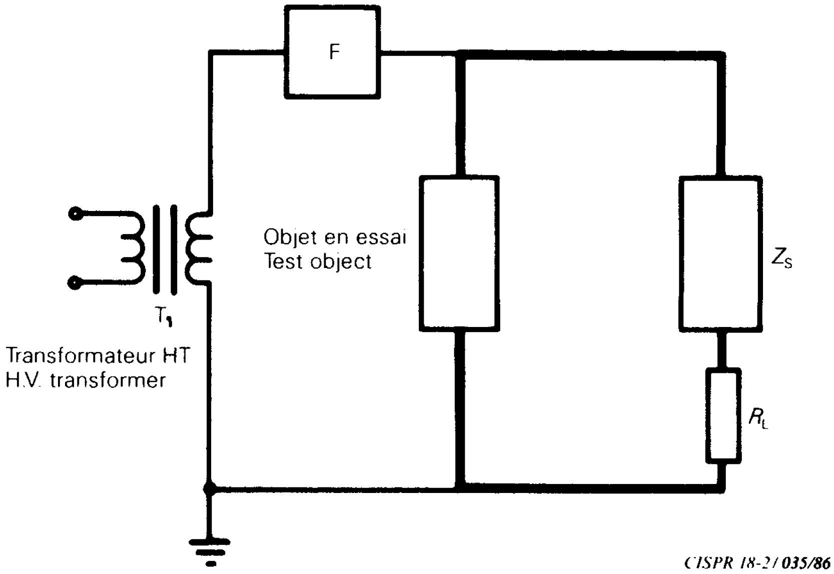
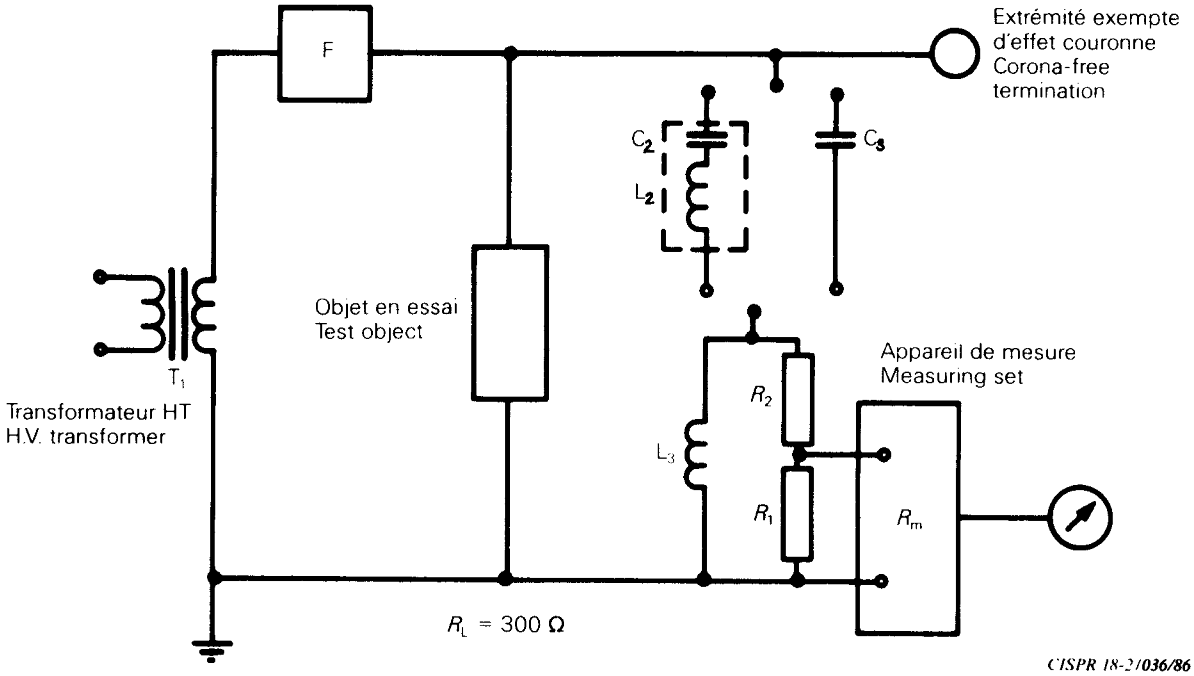


Figure 4 — Basic test circuit



NOTE Filter F may be aperiodic or consist of L_1 in parallel with C_1.

Figure 5 — Standard test circuit

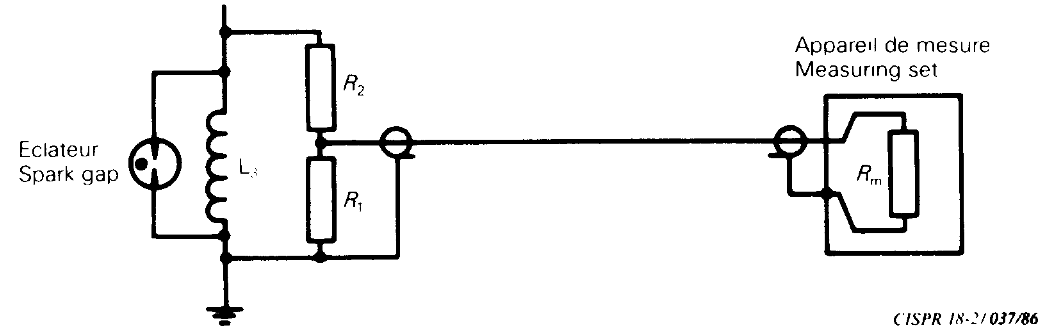


Figure 6 — Measuring set connections co-axial cable

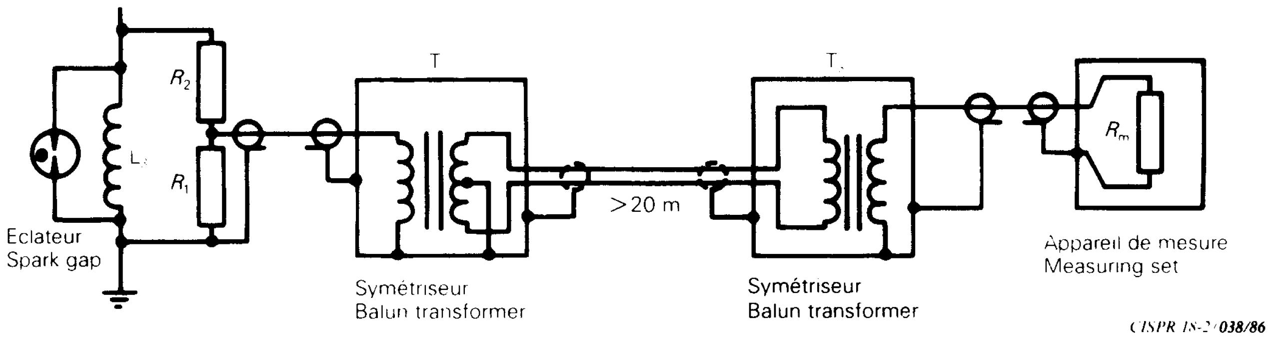


Figure 7 — Measuring set connections balanced cable

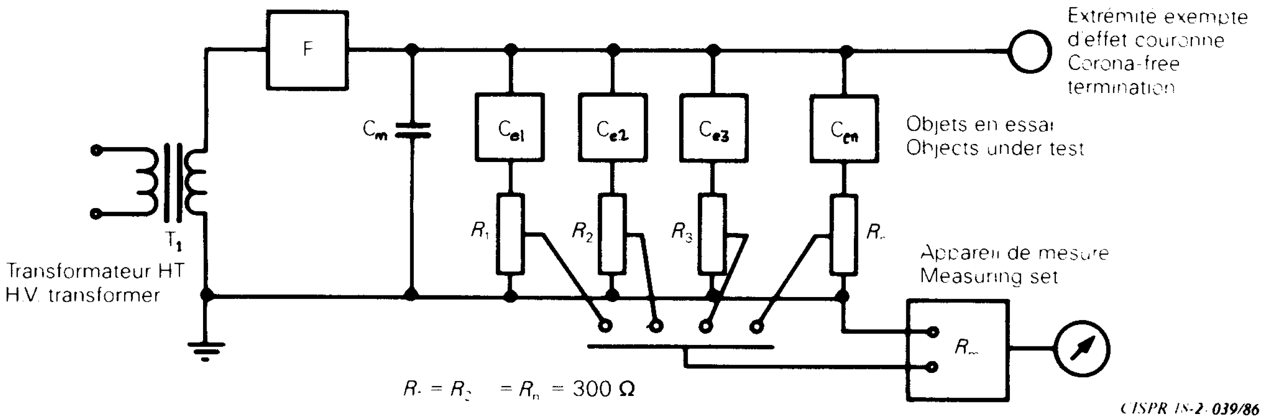


Figure 8 — Special test circuit

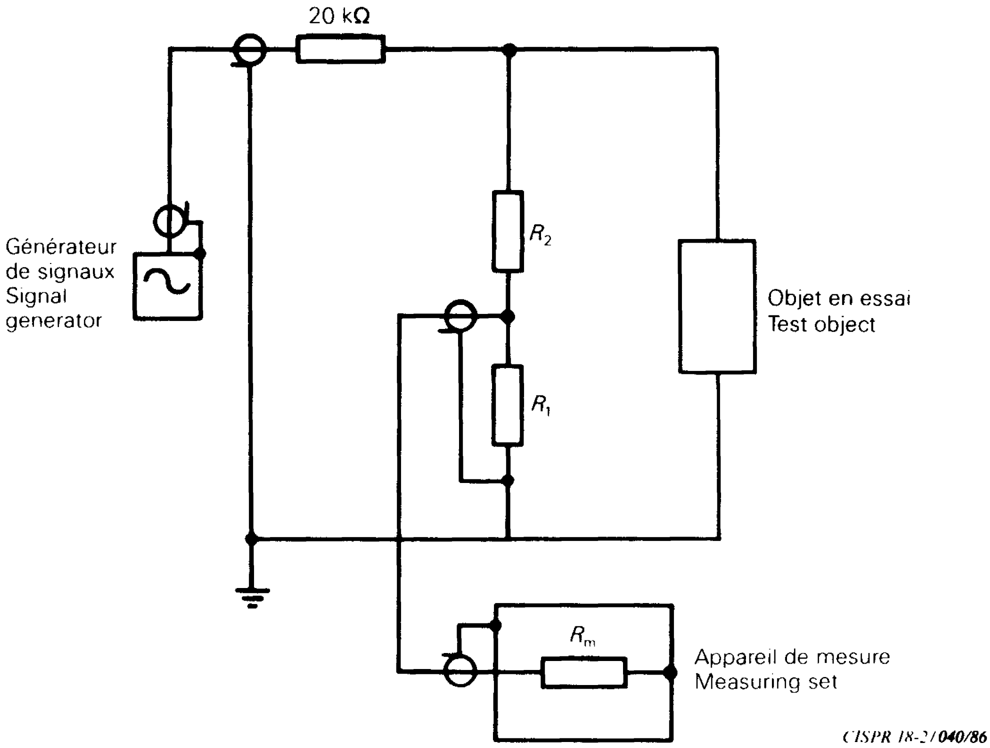


Figure 9 — Arrangement for calibration of standard test circuit

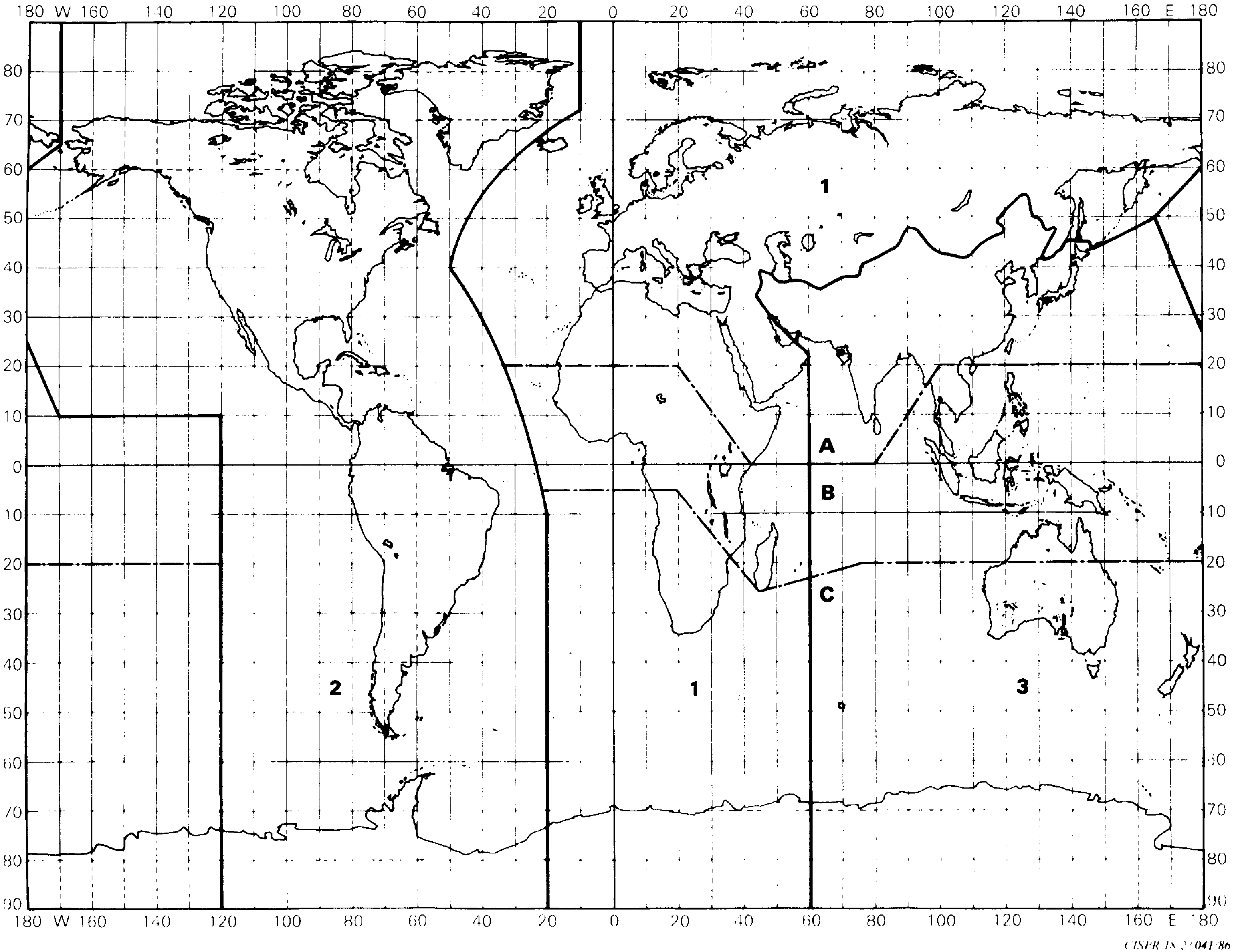


Figure 10 — Map showing boundaries of Zones A, B and C in Regions 1 and 3

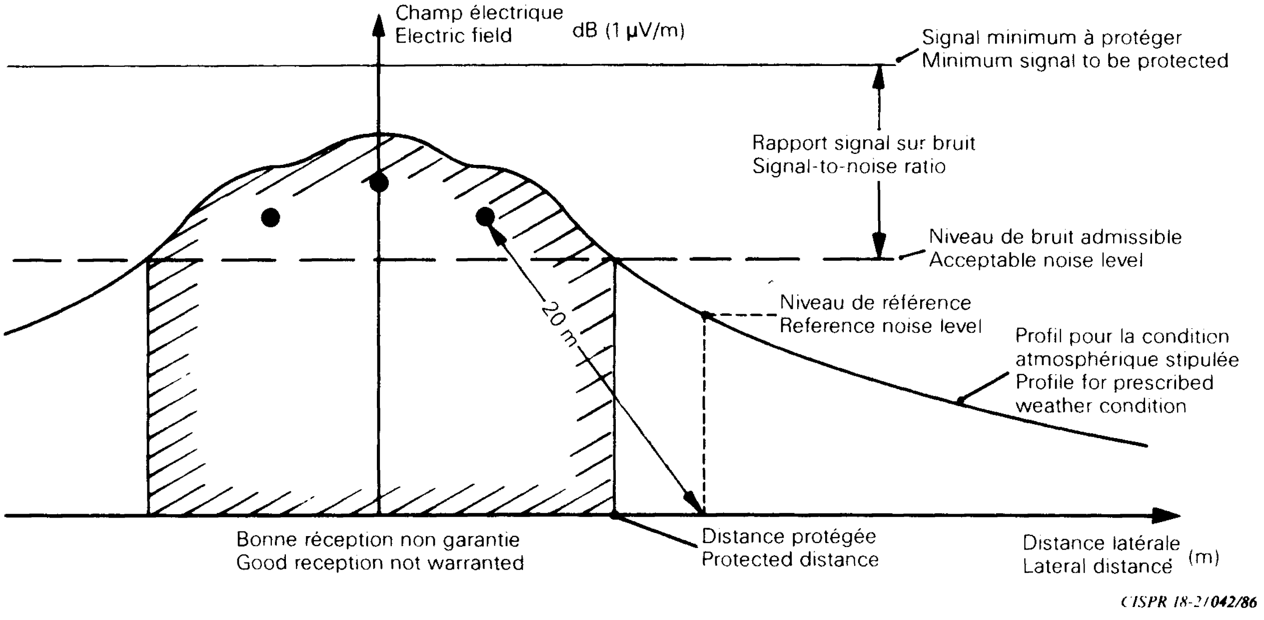


Figure 11 — Illustration of the four basic parameters

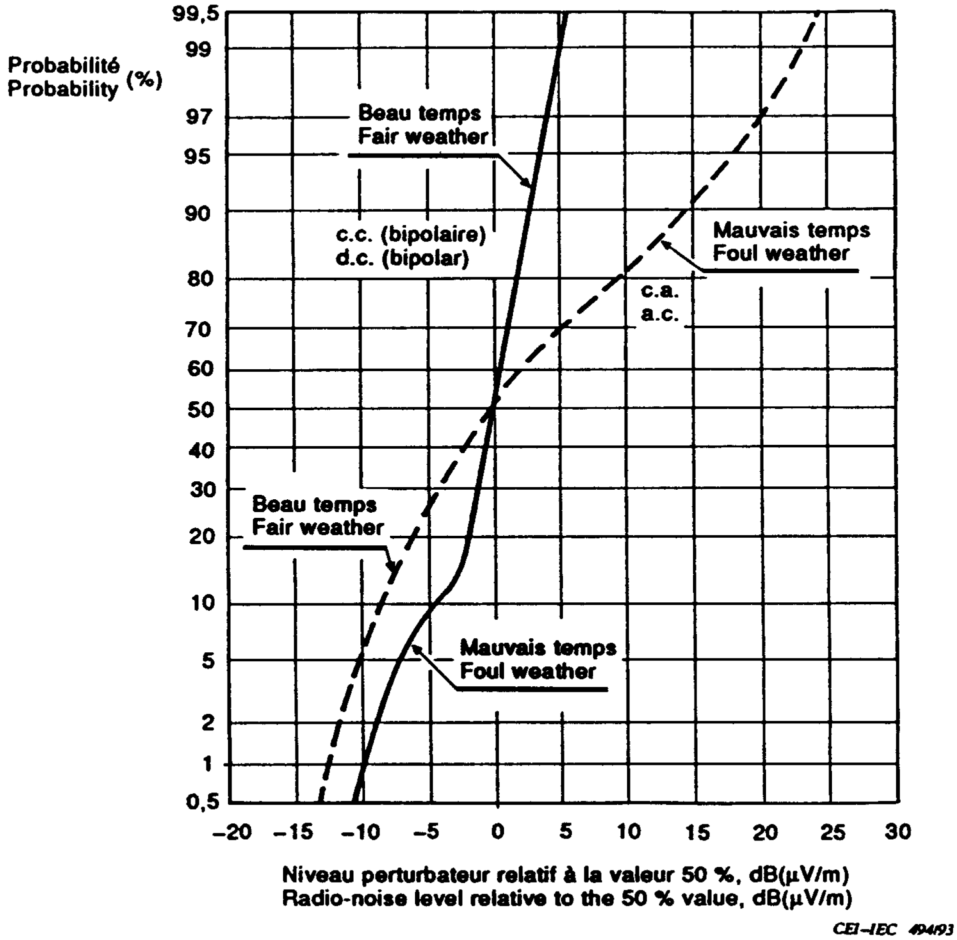


Figure 12 — Example of typical statistical yearly "all-weather" distributions of the radio-noise levels for a bipolar direct current line (—) and for an alternating current line in a moderate climate (– – –). The 80 % radio noise level corresponds to fair weather for the direct current line and to foul weather for the alternating current line

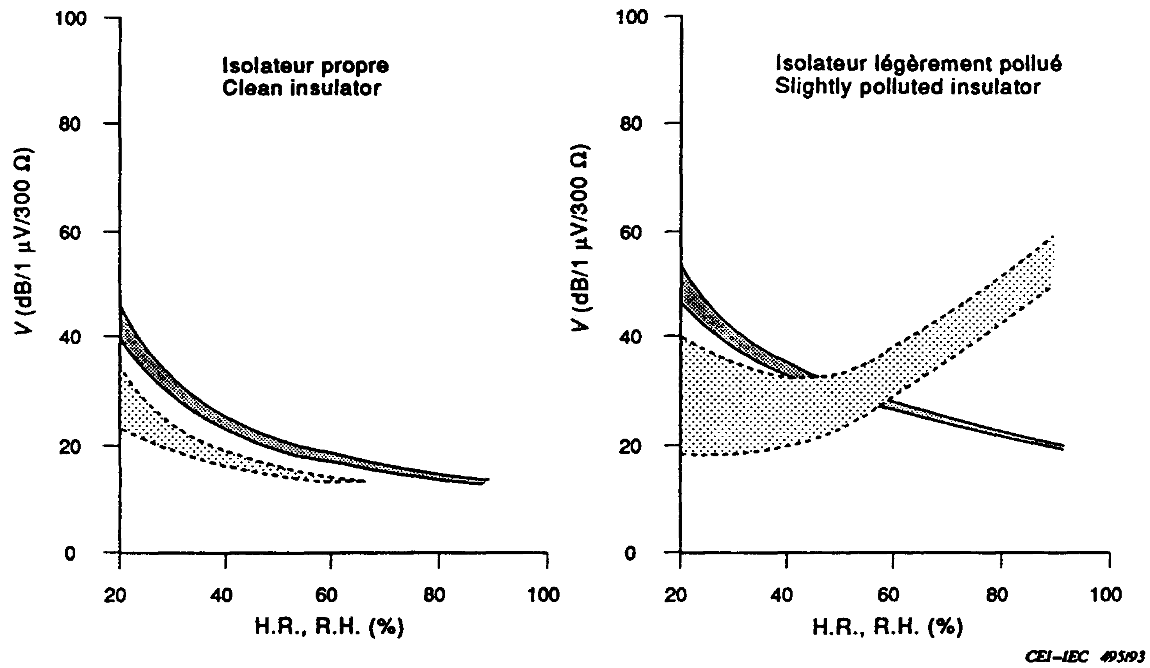


Figure 13 — Example of radio noise voltage level *V*, as a function of the relative air humidity R.H., in clean conditions and slightly polluted conditions, of a standard insulator (—) and a particular type of "low noise" insulator (– – –). Both insulators are glass cap-and-pin insulators of the same class (U120 BS as in IEC 305). For each insulator type one single unit was tested at a voltage of 14 kV

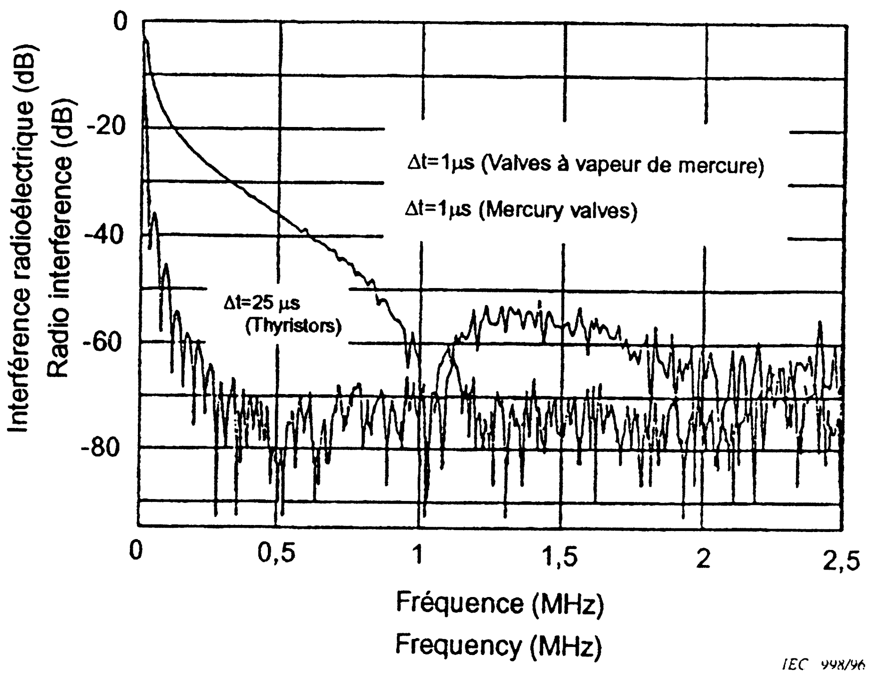


Figure 14 — Example of frequency spectra of pulses with different rise times, simulating commutation phenomena in mercury valves and in thyristor valves (see reference [80])

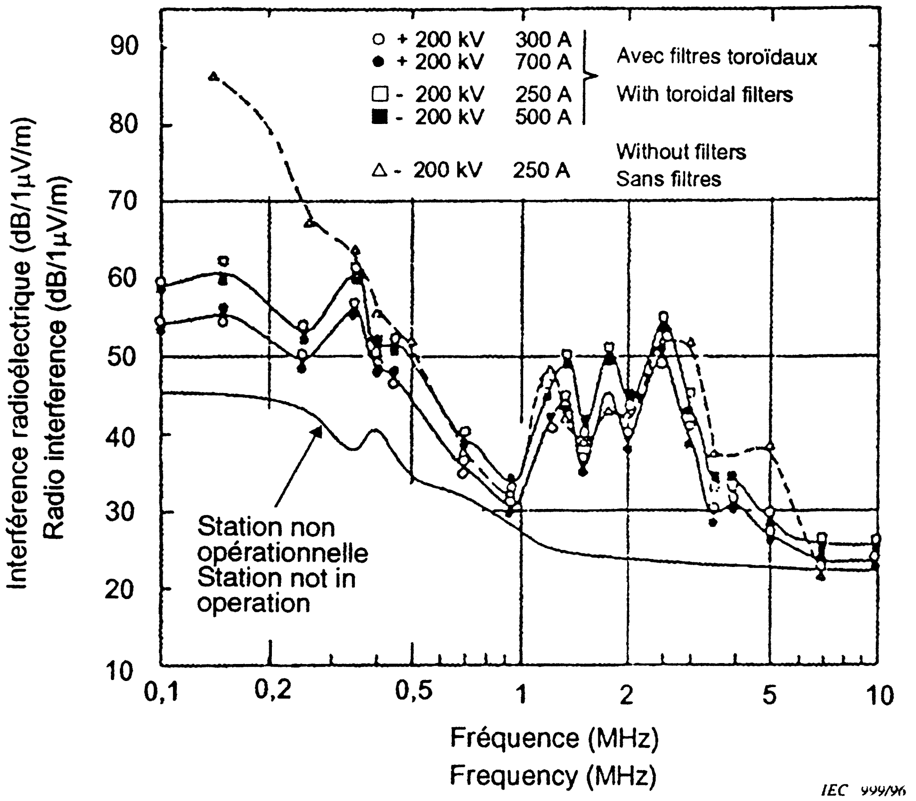


Figure 15 — Example of frequency spectra of the radio interference recorded outside the hall of a mercury arc valve converter station with and without toroidal filters (see reference [80])

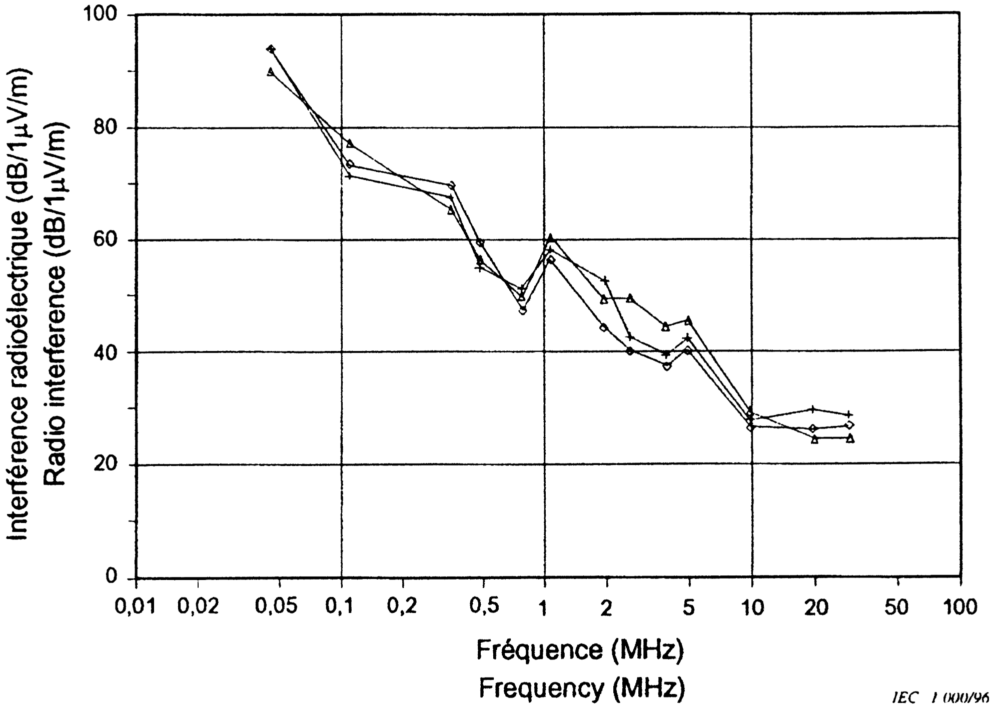


Figure 16 — Example of frequency spectra of the radio interference recorded outside the hall of a thyristor valve converter station for different operating conditions

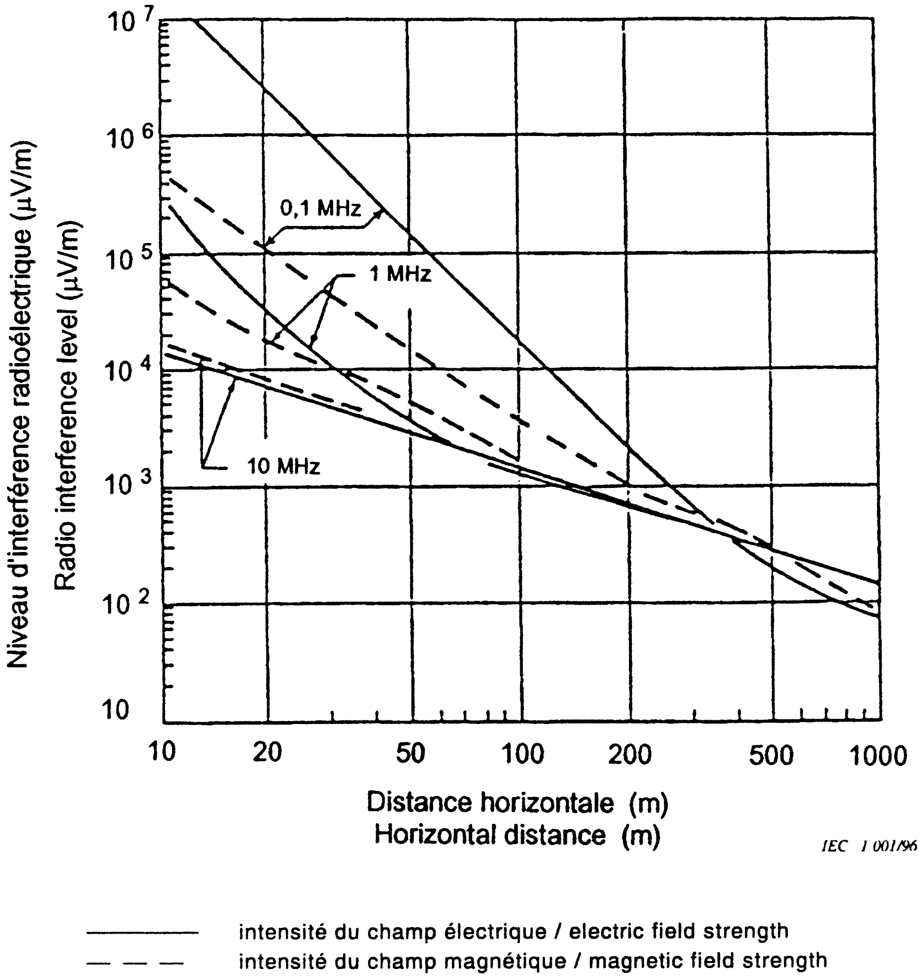


Figure 17 — Attenuation of the field strength as a function of the distance on a horizontal plane, for different frequencies (Calculated levels for free wave propagation of a radiation caused by a vertical electrical dipole; see reference [77])

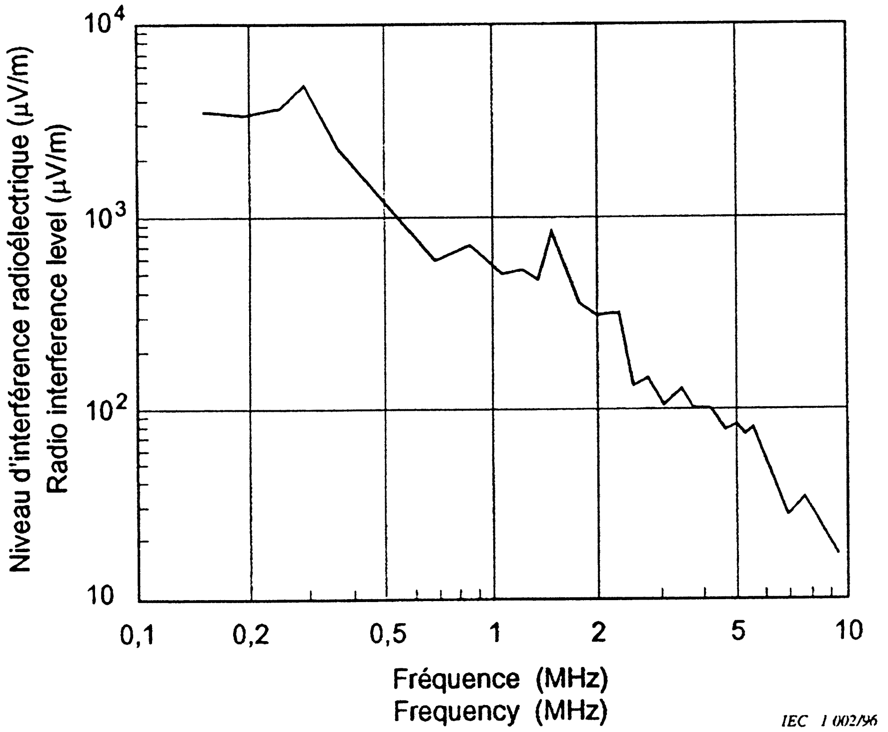


Figure 18 — Example of frequency spectrum of the radio interference in the vicinity of a d.c. line (30 m) at a short distance from the converter station (see reference [77])

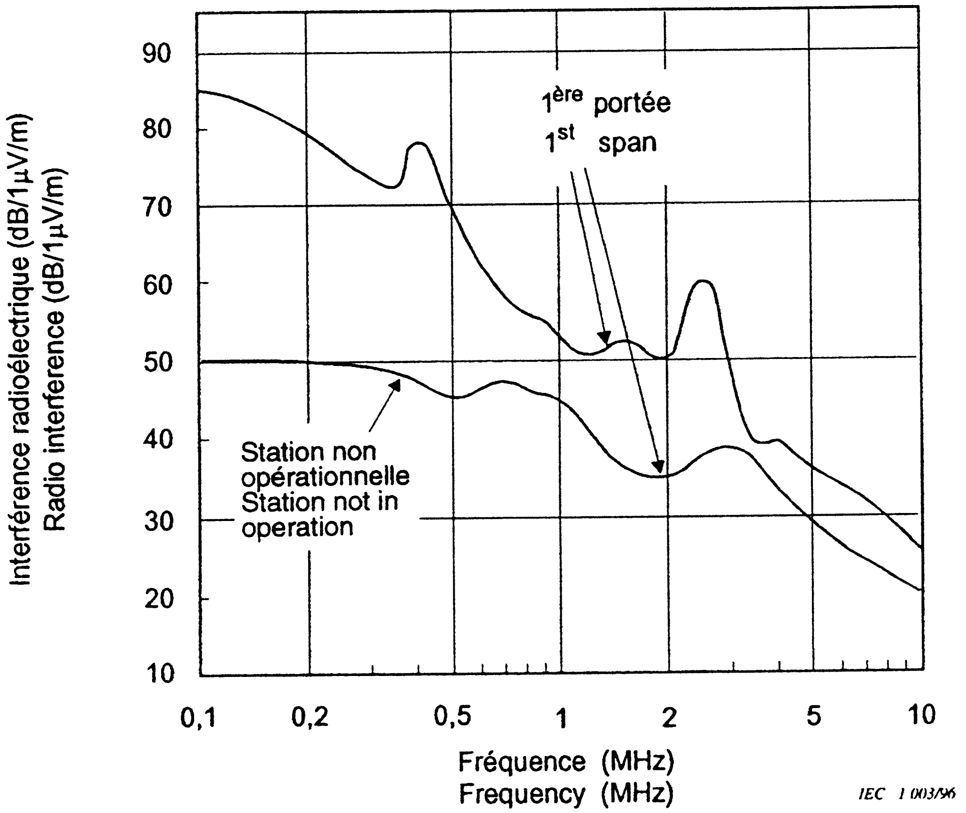


Figure 19 — Example of frequency spectrum of the radio interference in the vicinity of an a.c. line (20 m) at a short distance from the converter station (see reference [80])

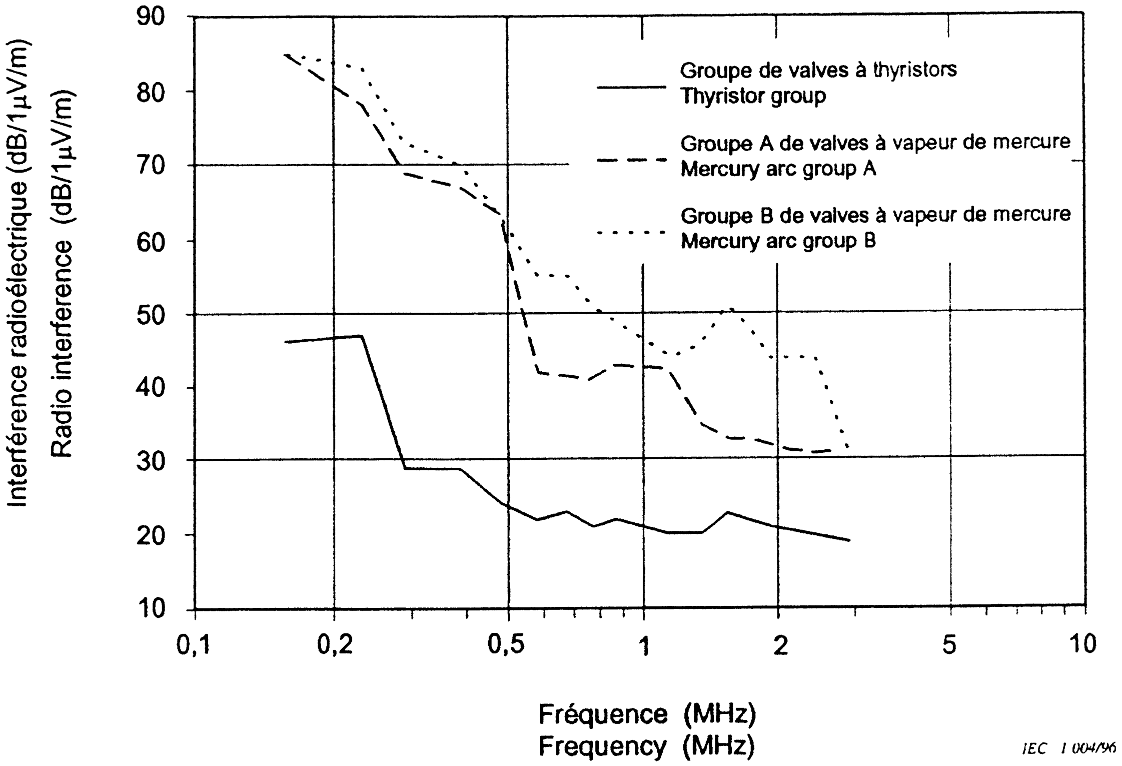


Figure 20 — Frequency spectra of radio interference at 20 m from the electrode line at 1,5 km from the Gotland HVDC link in Sweden with mercury arc groups or thyristor groups in operation

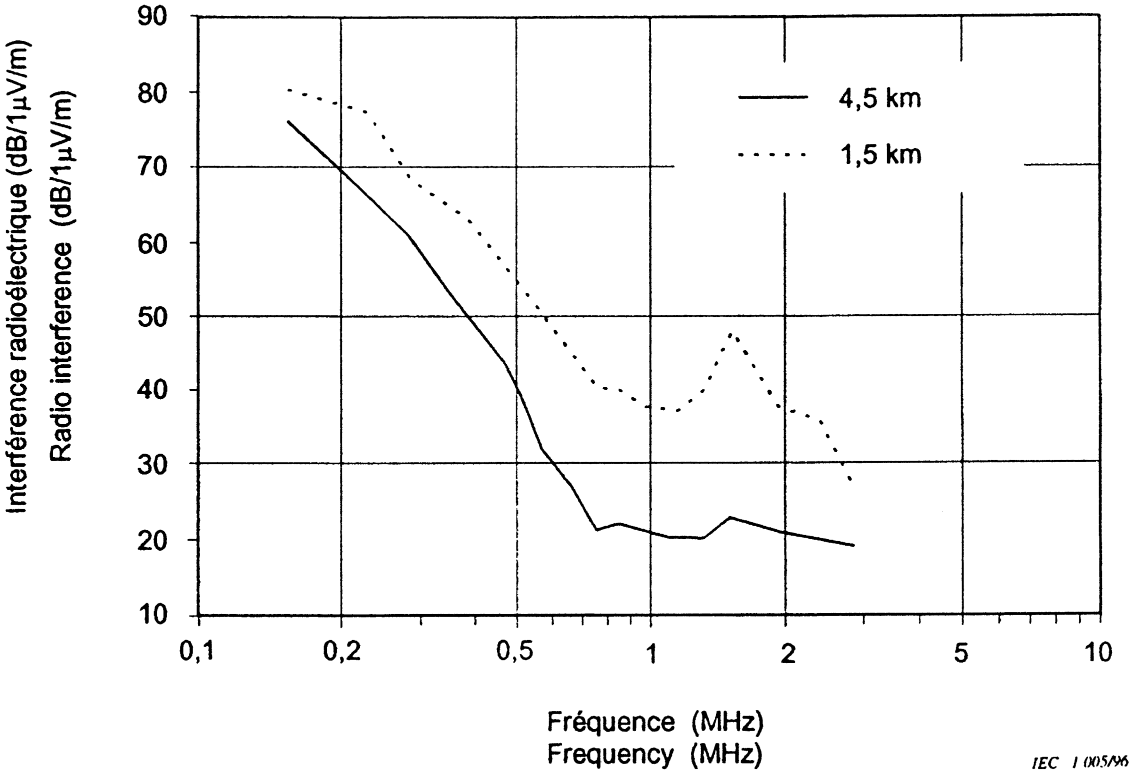


Figure 21 — Frequency spectra of radio interference at 20 m from the electrode line at 1,5 km and 4,5 km from the Gotland HVDC link in Sweden with mercury arc groups in operation

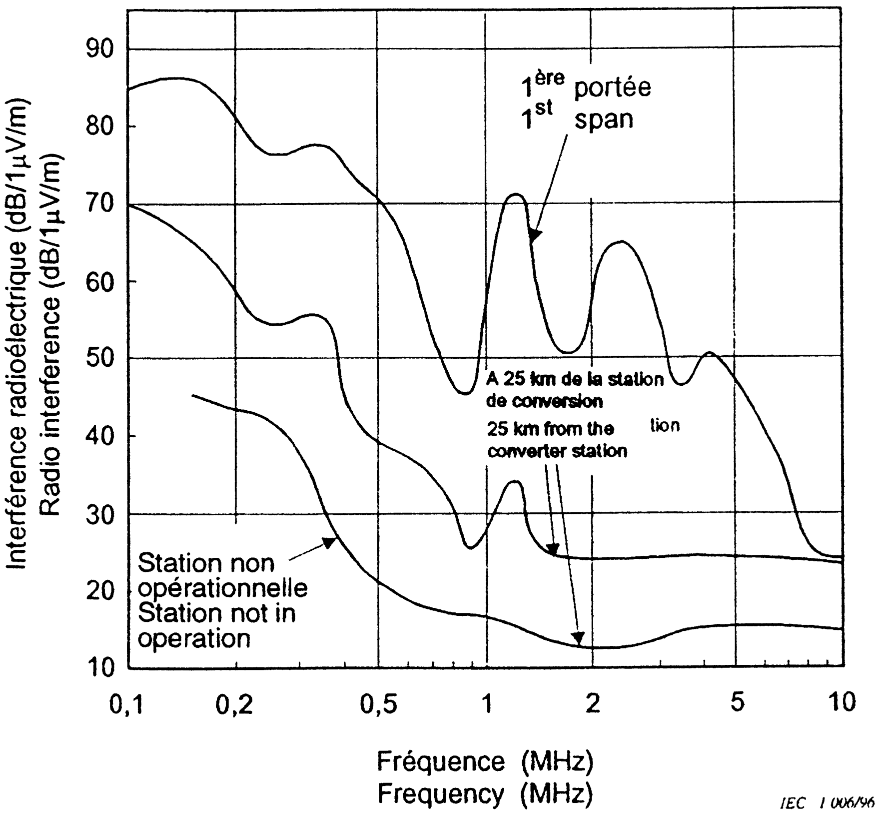


Figure 22 — Frequency spectra of the radio interference recorded along a 200 kV d.c. line, at 20 m from the conductor, at different distances from the converter station (see reference [80])

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Based on the above indications, the 80 % value of the noise current from the converting station, $I_{80\ \%\text{-cs}}$, may be put in relationship with the 80 % value of the line, $I_{80\ \%\ \text{l}}$, both expressed in dB, by means of the following formula.

$$I_{80\ \%\text{-cs}} = I_{80\ \%\text{–l}} + A + 20\ \text{Log}\ (n) - 10$$

n is the number of d.c. or a.c. lines;

A is the attenuation along the length of line for which an increase of more than 3 dB is accepted.

where

NOTE To verify that the radio interference level at a given lateral distance from the line complies with the criterion indicated above, the measurements should be performed at a longitudinal distance from the border of the converting station sufficient to avoid the superposition effect mentioned in 5.5 (more than 1 km, e.g. at 2,5 km).

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List of references

See national foreword.

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