ANSI C63.12-1999
(Revision of
ANSI C63.12-1987)

American National Standard Recommended Practice for Electromagnetic Compatibility Limits

Accredited Standards Committee on Electromagnetic Compatibility, C63

accredited by the

American National Standards Institute

Secretariat

Institute of Electrical and Electronics Engineers, Inc.

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Abstract: This recommended practice presents a rationale for developing limits and recommends sets of limits that are representative of current practice. These limits may be adjusted in particular applications as circumstances dictate.
Keywords: electromagnetic compatibility, electromagnetic noise, radio noise

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American National Standard

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Introduction

[This introduction is not part of ANSI C63.12-1999, American National Standard Recommended Practice for Electromagnetic Compatibility Limits.]

The problem of electromagnetic compatibility has existed from the early days of radio when spark gaps were used for transmitting and receivers picked up many signals unintentionally. Radio transmission has evolved from those early days into a highly sophisticated science. However, the need for compatibility is even greater today than it was in earlier times since modern society has come to depend on radio waves in all facets of life, from garage door openers and licensed broadcasting to sophisticated airplane and missile guidance systems. The proliferation of unintentional radiators, such as personal computers and video games, has increased the need for electromagnetic compatibility.

The need for an electromagnetic compatibility document was recognized by the American National Standards Committee C63 and as a result, the first official issue of C63.12 was approved 2 December 1983 and published by IEEE in 1984. Changes in national and international standards since that time prompted Committee C63 to request that Subcommittee Number 1 undertake a first revision, which was published by IEEE in 1988. Further changes in international and in military immunity techniques and requirements, as well as requests by potential users of C63.12, led to the current revision.

This recommended practice suggests emission limits based on maintaining existing ambient levels and protection of licensed radio services. Immunity limits are based on ensuring satisfactory equipment operation in the presence of likely disturbance levels due to man-made and natural noise sources.

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American National Standard Recommended Practice for Electromagnetic Compatibility Limits

1. Overview

Over the years many electromagnetic compatibility measurement and control standards have been developed. Many of these are of concern to particular classes of devices such as receivers, transmitters, incidental radiation devices, etc. In establishing limits, it is necessary to relate the measurement technique that is used to determine compliance with a given limit to the field conditions under which the device being controlled will actually operate. This recommended practice presents a rationale for developing limits[1] and recommends sets of limits that are representative of current practice. These limits may be adjusted in particular applications as circumstances dictate.

As part of the development of limits, the following parameters should be considered:

a) The general properties of both man-made and natural environmental electromagnetic noise (disturbances)[2]
b) An understanding of the devices commonly used for measurement of such disturbances and their properties, which will assist the practitioner in selecting such equipments and associated measurement techniques for the particular application
c) The rationale that can be used in selecting a consistent set of limits for emission and immunity (susceptibility), subject to various environmental constraints (good engineering practice)

These practices are intended to be applicable to individual equipments as well as systems of various sizes and, if properly applied, will provide guidance for obtaining both intrasystem and intersystem compatibility.

This recommended practice is organized as follows: Clause 2 references instrumentation and measurement methods; Clause 3 contains a list of definitions; Clause 4 describes environmental radio noise; Clause 5 describes the selection of measurement parameters; Clause 6 discusses limit setting; and Annex A is a bibliography.

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[1]It should be noted that the limits and measurement techniques described herein are proposed for general use to the extent that they are not covered in the regulations of the United States federal government agencies. Clearly, in circumstances where such regulations apply and could be considered to be in conflict with these practices, those regulations take precedence.

[2]The terms radio noise, electromagnetic noise, and electromagnetic disturbance generally connote the same phenomena, except that radio noise is restricted to phenomena at frequencies above 9 kHz. Otherwise, these terms are used interchangeably in this document.

2. References

Instrumentation and measurement methods used for determining equipment emission characteristics are described in more detail in ANSI C63.2-1996 and ANSI C63.4-1992. These documents should be reviewed before proceeding to make measurements. When standards referred to in this standard are superseded by a revision, the revision shall apply.

ANSI C63.2-1996, American National Standard Specifications for Electromagnetic Noise and Field Strength Instrumentation, 10 kHz to 40 GHz.[3]

ANSI C63.4-1992, American National Standard Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz.

ANSI C63.7-1992, American National Standard Guide for Construction of Open-Area Test Sites for Performing Radiated Emission Measurements.

ANSI C63.14-1998, American National Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD) (Dictionary of EMC/EMP/ESD Terms and Definitions).

CISPR Publication 11 (1990), Interference from industrial, scientific, and medical radio frequency apparatus.[4]

CISPR Publication 13 (1990), Limits and methods of measurement of radio interference characteristics of sound and television receivers, includes Amendment No. 1, April, 1992, Amendment No. 2, May, 1993 and Amendment No. 3, Jan, 1995.

CISPR Publication 22 (1993), Limits and methods of measurement of radio interference characteristics of information technology equipment. Second Ed. 1993.

FCC 47 CFR 15 B, Technical Standards for Computing Devices.[5]

FCC 47 CFR 18, Technical Standards for Industrial, Scientific and Medical Equipment.

FCC 47 CFR 68, FCC Rules for Registration of Telephone Equipment.

IEC 61000-4-2 (1995-01), Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 2: Electrostatic discharge immunity test.[6]

IEC 61000-4-3 (1995-02), Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 3: Radiated, radio frequency, electromagnetic field immunity test.

IEC 61000-4-4 (1995-01), Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 4: Electrical fast transient/burst immunity test.

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[3]ANSI C63 documents are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[4]CISPR documents are available from the International Electrotechnical Commission, 3, rue de Varembé, Case Postale 131, CH 1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). They are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[5]FCC publications are available from the Superintendent of Documents, U.S. Government Printing Office, Document Control Branch, Washington, DC 20402, USA.

[6]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

IEC 61000-4-5 (1995-02), Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 5: Surge immunity test.

IEC 61000-4-6 (1996-04), Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 6: Immunity to conducted disturbances induced by radio-frequency fields.

IEEE Std 473-1985 (Reaff 1997), IEEE Recommended Practice for an Electromagnetic Site Survey (10 kHz to 10 GHz).[7]

IEEE Std C62.41-1991 (Reaff 1995), IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits.

IEEE Std C62.45-1992 (Reaff 1998), IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits.

MIL-STD-461D, 11 Jan 1993, Requirements for the control of electromagnetic interference emissions and susceptibility, U.S. Department of Defense.[8]

MIL-STD-462D, 11 Jan 1993, Measurement of Electromagnetic interference characteristics, U.S. Department of Defense.

3. Definitions

For definitions of terms not included in this standard, see ANSI C63.14-1998.

3.1 amplitude probability distribution (APD): The fraction of the total time interval for which the envelope of a function is above a given level as a function of x.

3.2 atmospheric radio noise: Electromagnetic noise in the radio frequency range having its sources in natural atmospheric phenomena.

3.3 electromagnetic disturbance: Any electromagnetic phenomenon that may degrade the performance of a device, equipment, or system, or adversely affect living or inert matter.

3.4 electromagnetic noise: A time-varying electromagnetic phenomenon apparently not conveying information and that may be superimposed on or combined with a wanted signal.

3.5 environmental radio noise: The total electromagnetic disturbance complex in which an equipment subsystem or system may be immersed, exclusive of its own electromagnetic contribution.

3.6 intersystem electromagnetic compatibility: The condition that enables a system to function without perceptible degradation due to electromagnetic sources in another system.

3.7 intrasystem electromagnetic compatibility: The condition that enables the various portions of a system to function without perceptible degradation due to electromagnetic sources in other portions of the same system.

[7]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[8]MIL publications are available from Customer Service, Defense Printing Service, 700 Robbins Ave., Bldg. 4D, Philadelphia, PA 19111-5094.

3.8 noise amplitude distribution (NAD): A distribution showing the pulse amplitude that is equaled or exceeded as a function of pulse repetition rate.

3.9 random noise: Electromagnetic noise, the values of which at given instants are not predictable.

NOTE—The part of the noise that is unpredictable except in a statistical sense. The term is most frequently applied to the limiting case in which the number of transient disturbances per unit time is large, so that the spectral characteristics are the same as those of thermal noise. Thermal noise and shot noise are special cases of random noise.

4. Description of environmental radio noise

The minimum level required for satisfactory reception of desired radiated signals is determined by the level of environmental radio noise or undesired signals with which the desired signal must compete. Several types of radio noise may influence reception and consequent equipment operation; however, with a particular system and environment one type will generally predominate at a given time, especially if the receiving equipment is located physically near a specific source.

Sources of radio noise usually are divided into two general groups, those producing wide bandwidth and those producing narrow bandwidth noise, in which the distinction is usually based on comparison with the bandwidth of a typical receiver. Wide bandwidth noise is frequently impulsive and can be divided further into two groups, natural and man-made. Narrow bandwidth noise is usually generated by a variety of restricted radiation devices. These include industrial, scientific, and medical (ISM) equipments, licensed radio transmitters, and digital devices that produce line spectra at harmonics of the clock frequency. Restricted radiation devices generally radiate radio frequency energy over a limited portion of the spectrum clustered around discrete frequencies. Licensed radio transmitters radiate a noise spectrum near their carrier frequencies. The rapid proliferation of low-power portable transmitting sources has increased the need for consideration of the immunity (susceptibility) of electronic systems that must operate satisfactorily in close proximity to these sources.

To the extent that radio noise varies, a time domain statistical description is necessary to characterize it. Just how much detail is needed in the description depends upon the nature of the source, the desired accuracy of predicting degradation, and the information bandwidth of the system with which it may interfere. For many man-made sources the noise can be characterized as *stationary* whereas for natural sources, the noise may occur with variations having time periods ranging from fractions of a second to a year or more.

5. Measurement of radio noise

5.1 Introduction

In determining how to conduct measurements of radio noise sources, the following criteria should be kept in mind (IEEE Std 473-1985)[9]:

a) Since many measurements are usually required in many areas, parameters should be simple and economical to measure and analyze.
b) Parameters should be such that the interference effect of the noise on the various types of systems likely to be affected can be accurately judged.
c) Parameters should be such that they can be related to such predictors as, for example, population and vehicle density.
d) Parameters should be useful in identifying the source of the measured noise.

[9]Information on references can be found in Clause 2.

5.2 Selection of parameters

It is apparent that no single parameter can be selected as the best for measuring interference effects on a wide variety of services, for example, voice, telegraph, facsimile, analog or digital data, and television (TV). There is also a wide range of needed service quality. In the case of interference from atmospheric radio noise, a parameter that is related to occasional lightning flashes should be chosen if a very high quality of service is desired 100% of the time. Otherwise, a measure related more nearly to the average or rms level might be more meaningful.

5.2.1 Radio interference

Generally one can expect that radio communication receiving systems will have the greatest sensitivity to radio noise as they contain circuits that are usually much more sensitive than circuits used for local (wired) communications and control purposes. Furthermore, there has been an effort, particularly in data transmission, to use various coding techniques to improve the performance of radio circuits in the presence of fading and interference with varying degrees of success. In many cases, interference (or severe fading) tends to occur over limited periods of time and frequently is capable of destroying, during its presence, any signal however coded. This has led to the consideration of redundancy spaced in time rather than in frequency or space in order that occasional bursts of radio noise will not cause uncorrected or unnoticed errors in coded transmissions. The type of coding undoubtedly affects the weighting that should be given in deciding on noise measurement parameters.

The interference produced by an undesired continuous wave (CW) signal may depend critically on the phase and amplitude relationship between it and the desired signal. For example, in AM broadcasting, regulations require stations to maintain a ±20 Hz carrier tolerance in order to keep the beat note between stations on the same frequency inaudible. In this case, the interference originally caused by the carrier beats has been so reduced that the modulation from the interfering stations now predominates. Similarly, to reduce interference, 10 or 20 kHz frequency offsets of television stations are employed. Impulsive interference having certain repetition rates may prove especially destructive to TV reception. The design of the TV receiver synchronization circuit is critical in this regard.

If a communication system performance is degraded by a particular form of radio noise, the system might be redesigned to reduce the impact of that type of radio noise. An example is the use of limiters in FM and AM voice systems to reduce local impulsive radio noise effects. Thus, development of measuring methods should be closely allied to interference studies since the utility of the measurements will hinge largely on their correlation with caused interference.

Thus, the critical levels of particular forms of a disturbance can be quite dependent on the design of the receiving systems. The acceptable levels mentioned in this recommended practice assume the more common systems used in broadcast and point-to-point services.

5.2.2 Non-radio interference

Non-radio systems include control and local data transfer systems. Such systems operate at higher signal levels than radio systems and therefore usually can tolerate relatively high levels of disturbance. On the other hand, they may be located much closer to a particular disturbance source than a receiver antenna so that a single source (located, for example at an industrial site) may be quite capable of interfering with both types of devices at the same time.

5.3 Measurement of stationary distributions

For stationary distributions, relatively simple real-time logic functions can be utilized to measure certain characteristics of the distribution, such as the average, peak, root-mean-square (rms), quasi-peak, and average logarithm, rather than the distribution itself [B5][10], [B14]. One or more of the distributions can be used to predict the effects of a measured radio noise on the performance of a specific communication, navigation, or other electronic system provided the repetition rate, bandwidths of both the measuring and susceptible system, and other vital information are known.

5.3.1 Quasi-peak

Historically, radio noise measurements were first made to protect AM broadcasting. Burrill [B3] shows that the quasi-peak meter provides, on the basis of listening tests, good correlation of interference to AM receivers created by three different types of individual noise sources. There have been several sets of charge and discharge time constants used, in particular 1–600 ms, 1–160 ms, and 10–600 ms, depending upon the application and frequency range. These are described in ANSI C63.2-1995.

5.3.2 Peak

In the United States, peak measurements (either metered or slideback) have been widely used in military and civilian standards for measurements of impulsive (ignition) interference. As a means of evaluating the radiation from some incidental radiation devices, the peak reading meter is limited. For example, the radiated radio noise from between 1 and 100 ignition systems could produce the same peak reading while the associated power level would vary by 20 dB. Peak readings may also be used for emissions testing to reduce the time needed for testing. However, it must be recognized that peak readings may be many decibels higher than quasi-peak readings if the measured signal is not a constant amplitude signal.

5.3.3 RMS

The rms value has been used in the measurement of atmospherics and other forms of random noise. It has the advantage that it can be related to the spectral power density which, for noise with a flat spectrum, is independent of bandwidth. For some types of transmission it can be correlated quite well with interference effect.

5.3.4 Average

The average is used most commonly for measuring the level of modulated radio carriers. It is also used in characterizing atmospherics by means of the parameter V_d defined as the ratio of the rms to the average value. Thus, the average detector also can be used in combination with the peak or quasi-peak detector to determine if the measured emission is caused by an impulsive (broadband) or continuous wave (narrowband) source.

5.4 Statistical measures

References [B17], [B21], [B22], and others have given definitions and descriptions of the hierarchy of probability distributions required for the description of a random process. In practice it is almost never feasible to obtain this complete description for man-made disturbances. It has been found that, for additive interference (Gaussian, atmospheric, man-made, and the like), performance can be determined for most systems from the amplitude probability distributions (APD) of the disturbances and of the signal envelopes ([B1], [B7]). In addition, the noise amplitude distribution (NAD) has been measured frequently. Both distributions give

[10]The numbers in brackets correspond to those of the bibliography in Annex A.

detailed information about the disturbance and can be used to evaluate the effects of a given type of disturbance on a given communication system with varying degrees of accuracy.

However, since some forms of additive interference are correlated in time, higher order distributions are, in principle, also required for some systems. References [B2], [B6], [B11], [B20], [B23], and [B28] give specific examples of such studies for digital systems, while references [B17], [B19], [B26], [B27], and [B29] and their bibliographies treat systems in general and give specific examples for both analog and digital systems. For the optimum design of some communication systems, all of the above statistics may be required.

5.5 Effect of measurement bandwidth

Since any measurement of a disturbance is made on what is detected with a receiving system having a finite bandwidth and not on the voltages induced in the receiving antenna or sensor, the receiving system characteristics must be considered. That is, differences between the receiver experiencing interference and the receiver used in the measurement program must be taken into account. Indeed, interference appearing to originate in isolated impulses on one (wideband) receiver could appear as originating in overlapping disturbance bursts in another (narrow-band) receiver.

6. Limit setting

This clause develops the rationale for, and suggests guidelines for, the setting of permitted levels of electromagnetic emissions from various types of unintentional radiators. It also provides guidelines for immunity limits. A basis for establishing general interference/emission objectives is first developed, followed by examples of derivation of test specifications for specific equipments and allocation of emission requirements among multiple components of a system. Where specific limits have already been established by regulatory bodies, or, where appropriate, by agreement between the user and the manufacturer, those specific limits supersede limits herein. For use in environments containing especially sensitive receivers or in severe environments such as experienced in military operational environments, special limits may be required.

6.1 Emissions (protection of radio reception)

Interference with a radio frequency system or other susceptible equipment is a function of the magnitude and character of the radiated signal, the immediate electromagnetic environment, and the characteristics of the susceptible system or equipment. For economic reasons, the energy used in radio transmissions is normally the minimum required to achieve useful communication. This energy is a function of the ambient noise level at the expected location of the receiver.

A widely used summary of the anticipated median outdoor values of natural and man-made noise (expressed in terms of noise figure F_a in decibels above kTB, where k is Boltzman's constant, T is 290 Kelvin, and B is receiver bandwidth in Hz) is given in Figure 1 (See IEEE Std 473-1985).

Although broadband noise is accurately described by the power spectral density as in Figure 1, it is more common to prescribe limits on radiated noise in terms of electric field strength (see Footnote 11) as measured over a specified bandwidth. In Figure 2, sloping dotted lines representing constant field strength are super-imposed on Figure 1. They correspond to the field strength as seen by a receiver of 10 kHz bandwidth using an electrically small nondirectional antenna. The 10 kHz bandwidth is taken as typical of many communication receivers and of AM broadcast receivers in particular. Figure 2 also shows expected values of atmospheric noise, which, although quite variable depending on local atmospheric conditions, typically can exceed local values of man-made noise at frequencies below about 2 MHz.

It should be noted that the *quiet rural areas* curves of Figure 1 and Figure 2 represent locations chosen to be as free as possible of man-made noise. The presence of even a small number of automobiles, power lines, or business or residential machines would change the environmental conditions to those of the *rural areas* curve. The ambient noise median is fairly constant in the range of 5–25 dB (μV/m) at higher frequencies as set by man-made noise and increases at frequencies below about 2 MHz as set by atmospheric noise [B1], [B4], [B7], [B8], [B10], [B12], [B15], [B24], [B25].

The choice of the particular numbers to be used for guidelines to meet noninterference objectives is not amenable to exact analysis. Data are not available describing the relation between a given emission limit and the number of interference cases observed or of the impact of various levels of radiation reduction. The general approach that has been used is that the permitted emission levels at a somewhat arbitrary, but specified distance from a given radiating source should not raise the noise level above the atmospheric noise. This specified distance is sometimes referred to as the *protection distance*.

The adoption of two protection distances, one for equipments used in a residential (Class B) environment and the other for equipments used in an industrial (Class A) environment, has the potential for reducing costs while still providing adequate protection. Thus, one set of limits applies to equipments used in a commercial/industrial environment where the ambient noise level tends to be high and the likelihood of sensitive receivers is low. A second stricter emissions limit applies to equipments that will be operated in a residential/domestic environment where noise levels tend to be lower and where there are generally larger numbers of sensitive receivers.

The distance at which the radiated emission should be measured could reasonably vary from as little as one meter to as much as several tens of meters. This distance is primarily limited at the close range by the problems of making accurate measurements in the nearfield region. At distances much in excess of 30 m the levels of device emissions that will meet the requirements will, in many cases, be at the same as or lower than the ambient noise level and may not be capable of resolution. A limit specified at a measurement distance of somewhere between 3 m and 30 m is preferred when measurement logistics and typical noise source, receiver, and antenna characteristics are considered.

Typically, the distance is set at 3 m or 10 m when measurements are made on a test site. Measurements at less than the limit distance, for example, measurements at 3 m when the limit distance is 10 m, may be used if the results are carefully extrapolated to the limit distance. Extrapolation is discussed in Footnote 11.

Emission measurements should be made in accordance with ANSI C63.4-1992. ANSI C63.7-1992, IEEE Std 473-1985, FCC 47 CFR 15 B, and CISPR Publications 13 and 22 give further information on recommended emission test site characteristics and measurement procedures.

Equipment manufacturers and users are advised to refer to any appropriate standards that may apply to their particular types of equipments. ISM radio frequency equipment limits are covered in FCC 47 CFR 18 and CISPR Publication 11. Stricter emission limits may be required for special situations such as on-board aircraft [B9] or for military applications (MIL-STD-461).

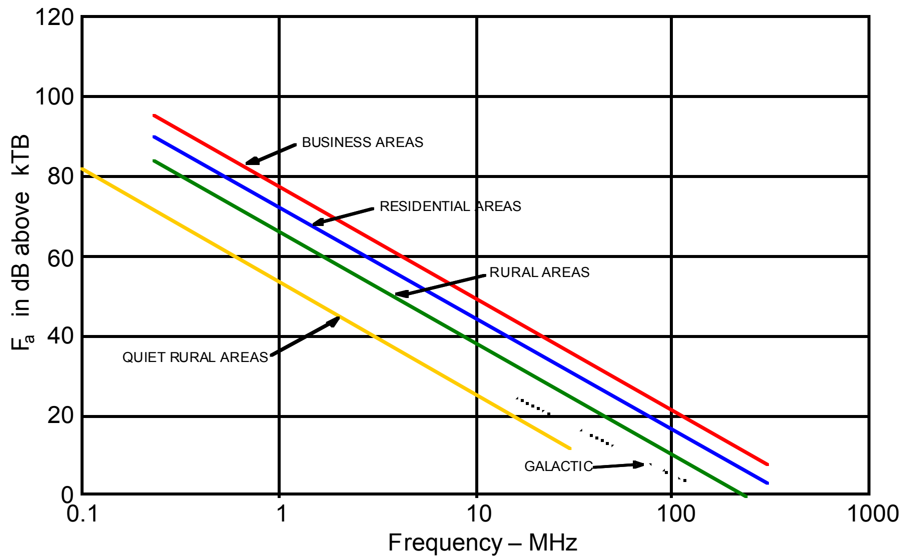

Figure 1—Median values of radio-noise power (omnidirectional antenna near the surface of the earth) (From reference [B24])

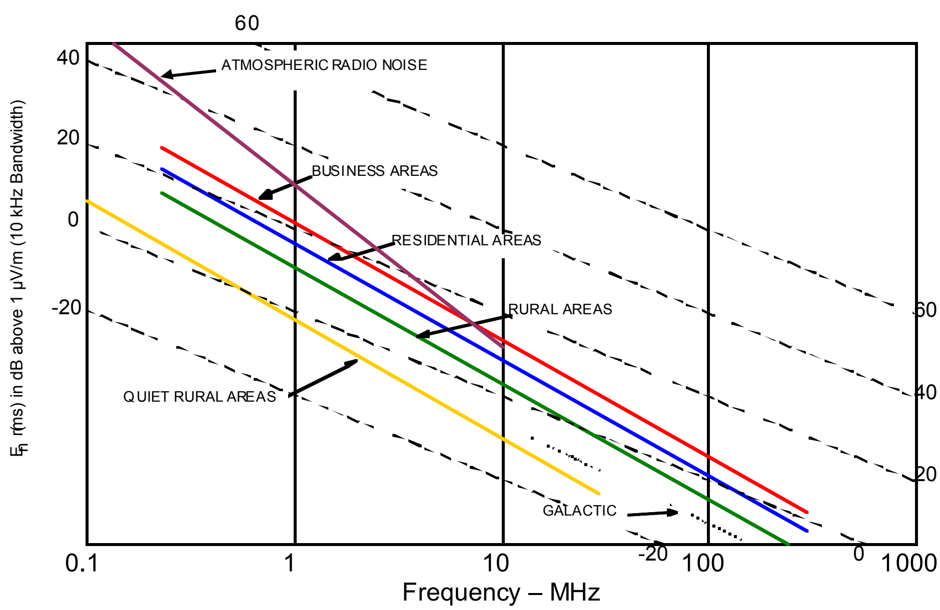

Figure 2—Median values of radio noise (omnidirectional antenna near the surface of the earth) (Converted to field strength from Figure 1)

6.1.1 Radiated emissions-general guidelines

In the absence of any other standards, the following requirements will assure that a reasonable level of protection is given to radio receivers operating in the vicinity of the equipment to which these standards are applied.

The general radiated emission guideline is shown in Figure 3 and Table 1. The levels given here and on later figures and tables are for narrow-band (modulated sine wave) emissions. For broad band emissions, a nominal 10 kHz bandwidth is assumed in the frequency range up to 30 MHz and 100 kHz above that. However, adjustments in level or the bandwidth may be appropriate depending on characteristics of the potentially susceptible equipment. For frequencies below 800 kHz, the permissible noise level increases inversely with frequency in approximate conformance to the atmospheric noise curve of Figure 2. Above 800 kHz, the level is constant to 230 MHz where the permitted level increases by 7 dB. At those higher frequencies, the limit is permitted to rise with respect to the ambient to allow for the gain effects of increased receiving antenna directivity. With regard to the broad frequency range covered in Figure 3, it should be noted that for many equipments, for example, appliances, because of their emission characteristics, it is customary to apply conducted measurements only below 30 MHz, and radiated measurements only above 30 MHz (see Table 3 through Table 6). Limits above 1 GHz are still under consideration.

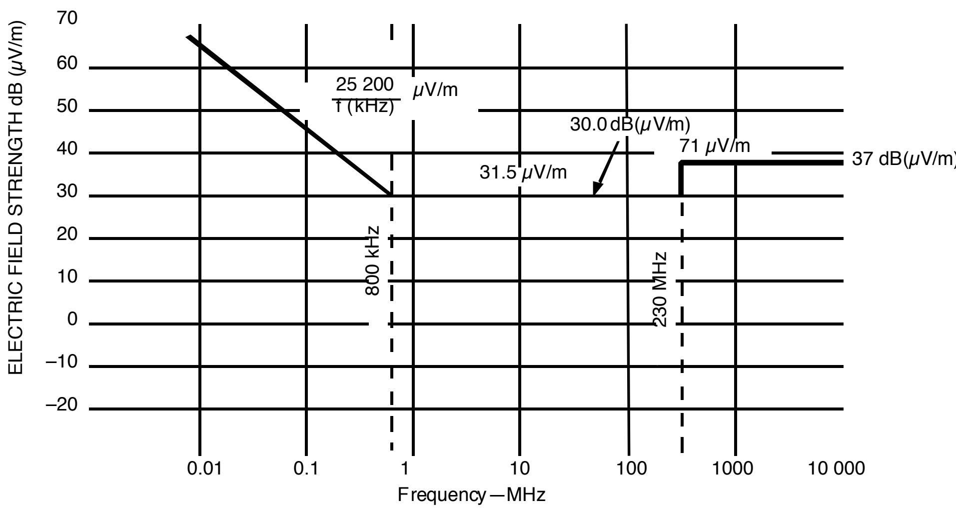

Figure 3—Radiated emission guidelines for a residential/domestic environment measured at a 10 m antenna distance, with a quasi-peak detector up to 1 GHz and a peak detector above 1 GHz.
(The guideline for the industrial environment is 10 dB higher)

Table 1—Radiated emission guidelines of Figure 3 in tabular form

Frequency of radiated emission	Field strength (μV/m)[a]	Field strength [dB(μV/m)][b]
Below 800 kHz	25 200/f[b]	88.0–20log f[b]
800 kHz to 230 MHz	31.5	30
230 to 1000 MHz	71	37
1000 to 10 000 MHz[c]	71	37

[a]Detector is quasi-peak up to 1 GHz and peak above 1 GHz.
[b]Where f is frequency in kilohertz. (The stricter limit shall apply at the transition frequency.) Measured at 10 m.
[c]The limit in this frequency range is still under consideration along with its extension to 60 GHz.

In general the measuring distance should be no less than the largest dimension of the device being measured and no less than the largest dimension of the measuring antenna. If at all possible, measurements should be made at the specification distance to avoid extrapolation of limits.[11]

6.1.1.1 Radiated emissions—residential limit

To protect radio reception in residential areas (Class B environment), the requirements of Figure 3 and Table 1 apply directly at a measurement distance of 10 m.

6.1.1.2 Radiated emissions—nonresidential limit

Nonresidential areas generally have a higher acceptable background noise level due to the presence of heavy machinery, and the fact that sensitive receivers are less likely to be used in those immediate areas. Therefore, the recommended emission limits of Figure 3 and Table 1 are relaxed by 10 dB to implement a protection distance of 30 m.

6.1.2 Conducted emissions—general guidelines

From an Electromagnetic Interference (EMI) standpoint, conducted emission phenomena and effects on power cables are different from those in signal cables. On power cables disturbances generated by one equipment may be conducted to other equipments connected to the same power system. The limits for such interference are set based upon a compromise determined by the sensitivities of the equipments that may be affected and the possibilities of filtering the disturbances at both the emitter and the susceptor cabinet cable entrance (or exit) point.

On the other hand, signal cables are usually connected between well-defined equipments for each of which the specifications of tolerable levels of undesired noise (or disturbances) can be determined beforehand. Of more concern on signal cables is the possibility of common-mode currents that can radiate and thus disturb equipments to which the cables are not directly connected. Limits on such emissions can be directly related to the radiated limits discussed in 6.1.1.

There can be relations between common-mode and differential-mode phenomena but, from a practical point of view, it has not been customary to place differential-mode emission limits on signal cables. However, limits on signal lines are being considered for the future for particular devices. Furthermore, because of the more complicated measuring system required to measure differential-mode emissions, it is conventional to measure only the voltage to reference ground on each conductor of a power cable. Thus, there is not a one-to-one correspondence between the common-mode current limit and the line-to-ground voltage limit.

A recommended common-mode current emission limit is shown in Figure 4. It is derived from the previously defined radiated emission level of Figure 3. The model used to convert from radiated emission to conducted emission was a one-meter vertical monopole, representing a vertical section of cable connecting to an

[11]It is understood that a radiation level expressed (as shown in Figure 3) in mV/m implies electric and magnetic field levels related by the free space impedance of 377 Ω. It is true that the free space impedance may not hold in the near field, that is, at frequencies where the measuring distance is less than $\lambda/2\pi$ where λ is the wavelength in meters (frequencies below 1600 kHz for a measuring distance of 30 m; frequencies below 4800 kHz for a measuring distance of 10 m and below 16 MHz for a measuring distance of 3 m). Extrapolation of the electric field limit values at a particular frequency to a different measuring distance requires a knowledge of the source of the emissions and the effects of a conducting ground plane over which these measurements are usually performed. In the simplest case, this would be either a small electric dipole or a small magnetic loop. In a free field, extrapolation of the limits at a particular frequency to distances less than $\lambda/2\pi$ requires extrapolation of the level at that frequency back to the $\lambda/2\pi$ distance using a $1/d$ extrapolation and then further extrapolation from the level at the $\lambda/2\pi$ distance to the final distance using a $1/d^3$ or $1/d^2$ relation (depending on an electric or magnetic source, respectively). Extrapolation of the limits at a particular frequency to distances greater than $\lambda/2\pi$ requires that the level at that frequency first be extrapolated to the $\lambda/2\pi$ distance using a $1/d^3$ or $1/d^2$ relation (depending on whether the source is electric or magnetic, respectively) and then further extrapolating the limit from the $\lambda/2\pi$ distance to the final distance using a $1/d$ relationship. It follows that limit extrapolation for distances greater than 3 m above 16 MHz, 10 m above 4800 kHz or 30 m above 1600 kHz requires only a simple $1/d$ extrapolation. Thus, translation of the guidelines requires a knowledge of the type of source causing the emissions, and may require experimental validation, especially to account for ground plane effects.

equipment unit [B18]. This model is most representative of common-mode vertically polarized emission sources, which are the sources most commonly seen. Similar levels would be obtained for horizontally polarized sources above a ground plane. This is based on a 10 m protection distance. (See Table 2.)

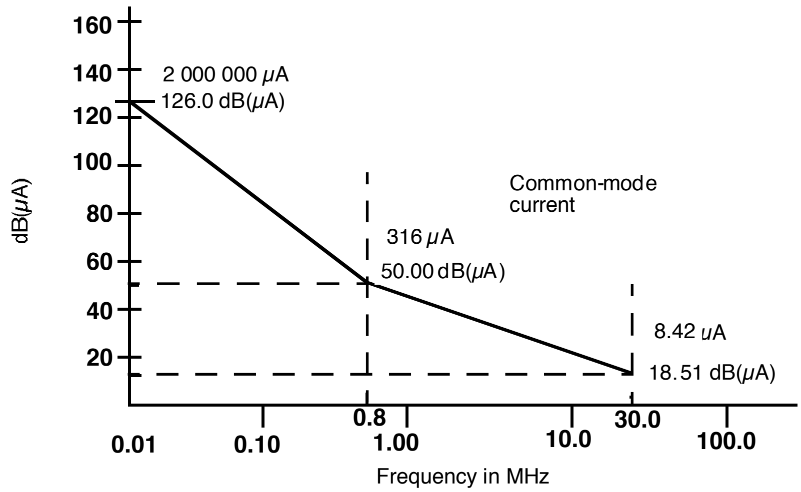

Figure 4—Common-mode conducted emission guidelines

Table 2—Common-mode conducted emission current guidelines

Emission frequency	Common-mode current dB(μA) (quasi-peak)
10 to 800 kHz	66 – 40 log *f* (kHz)
800 kHz to 30 MHz	48 – 20 log *f* (MHz)

One method of making the test that uses a current probe to measure the common-mode currents in shielded and nonshielded cables is given in ANSI C63.4-1992.

In addition to the above guideline, the use of a line-impedance stabilization network (LISN) to measure the disturbance voltage on ac power leads is recommended in ANSI C63.4-1992 and in CISPR Publications 11 and 22. The recommended AC power line limit voltages measured with an LISN for equipments to be used in a residential/domestic environment are shown in Table 3.

For equipments designed to be operated in a commercial/industrial environment the limits are as shown in Table 4. Those limits are recommended to provide protection for equipments located 30 m or more from the emitting equipment. Different limits may be more appropriate for other applications. For example, limits for conducted emissions above a frequency of 4 kHz from terminal equipments intended for connection to the public telecommunications network may be found in FCC 47 CFR 68.

Table 3—AC power-line conducted emission voltage guidelines—Residential/domestic

Frequency range (MHz)	Quasi-peak dB(μV)	Average dB(μV)
0.15 to 0.50	66 to 56	56 to 46
0.50 to 5.0	56	46
5 to 30	60	50

NOTE—The guideline decreases linearly with the logarithm of the frequency in the range 0.15 to 0.50 MHz. The stricter limit applies at the transition frequencies.

Table 4—AC power-line conducted emission voltage guidelines—Commercial and industrial

Frequency range (MHz)	Quasi-peak dB(μV)	Average dB(μV)
0.15 to 0.50	79	66
0.50 to 30	73	60

6.1.3 Generic emission requirements

Generic emission requirements have been developed to provide specific requirements for application where no other regulation or specific product standard applies. The requirements are given in Table 5 and Table 6 for residential/commercial and industrial installations, respectively (see CISPR Publications 11, 13, and 22 for specific product requirements), taking into consideration the distinction in the two classes of environments discussed in 6.l. Note that these limits are somewhat different from those discussed in 6.1.1 and 6.1.2.

The manufacturer needs to determine in which radio frequency environment (Table 5 or Table 6) the product is likely to be used and/or marketed, and, in fact, in which country the manufacturer wishes to meet emission regulations. In the European Union, in contrast to practice in the United States, the limits in Table 5 are applied not only for the residential environment, but also the commercial and light industry environments, or wherever the product is powered from the public mains supply. Correspondingly, the limits in Table 6 apply only for (heavy) industry where the product is powered from a non-public (industrial) supply.

6.1.4 Radiated and conducted emissions, special conditions

Under certain circumstances, different ambient levels may exist and different protection distances or levels may be appropriate. In such cases, for example, the relaxation of the limits for industrial areas may not be appropriate, and the residential limit might be considered as an alternate. Still other limits might be appropriate for equipments that might be used on aircraft with sensitive navigation equipment which operates in the fuselage in an ambient noise environment well below that shown in Figure 1.

Table 5—Generic emission requirements—Residential

	Frequency	Limits		Test method
Radiated	30 to 230 MHz 230 to 1000 MHz	30 dB(μV/m) at 10 m QP[a] 37 dB(μV/m) at 10 m QP		ANSI C63.4-1992
Power-line conducted	0.15 to 0.5 MHz 0.5 to 5 MHz 5 to 30 MHz	Average 56 to 46 dB(μV) 46 dB(μV) 50 dB(μV)	Quasi-Peak 66 to 56 dB(μV) 56 dB(μV) 60 dB(μV)	ANSI C63.4-1992

[a]quasi-peak

Table 6—Generic emission requirements—Commercial and industrial

	Frequency	Limits		Test methods
Radiated	30 to 230 MHz 230 to 1000 MHz	40 dB(μV/m) at 10 m QP[a] 47 dB(μV/m) at 10 m QP		ANSI C63.4-1992
Power-line conducted	0.15 to 0.5 MHz 0.5 to 5 MHz 5 to 30 MHz	Average 66 dB(μV) 60 dB(μV) 60 dB(μV)	Quasi-Peak 79 dB(μV) 73 dB(μV) 73 dB(μV)	ANSI C63.4-1992

[a]quasi-peak

6.1.5 Emission allocation for components of a large system

When a system is comprised of a number of differing subsystems or of multiple subsystems, such that the entire system appears to be or is measured as a single noise source, it is frequently desirable to allocate the permitted emissions among each of the subsystems. This requires knowing the expected number of each of the subsystems, the physical location of the subsystem in relation to the whole system, and anticipating the additive nature of the emissions from each of the subsystems (due to synchronous or non-synchronous operation of the subsystems). Cabling, physical placement of the subsystems, and cabinet resonances add to the difficulty of predicting the additive effects of multiple subsystems. The worst-case scenario would be doubling of the emissions, field strength, or voltage for every doubling of a subsystem when the subsystems are frequency and phase locked, and where each of the subsystems was physically located such as to directly illuminate the measuring antenna from the same distance. The best-case scenario would be no increase in the emissions level when the subsystems differ in frequency by an amount larger than the required measuring bandwidth. Two subsystems running at the same frequency, but not synchronized, would have emissions added on a power basis. If it is permitted by whatever legal entities have jurisdiction, building wall attenuation may be included in calculating the subsystem allocations.

There are two empirically based methods that may be used in allocating emissions that may be used in the absence of any other prescribed allocation procedure. One is based upon the number of subsystems and physical configuration of those subsystems, as described previously. A second method is based purely upon the input power to each of the subsystems, using the concept that the allocated emissions from a subsystem should be proportional to the ratio of that subsystem's power input to the total power input of a system having a similar level of EMC design.

Allocation procedures should be coordinated across all subsystems to ensure that the final results are as expected. Neither of the two rule of thumb methods presented are foolproof, but represent good methods to be used for initial allocation of emissions. A conservative estimate based on either of the procedures would add an additional 6 dB for measurement errors (included in the equations for the first method), and at least an additional 3 dB to provide for the inevitable inaccuracies involved in predicting how emissions will add (due to cabling, resonances, etc.).

6.1.5.1 Allocation method 1

Based upon empirical observations for similar synchronously operated subsystems measured in a common system, the margin M required for a subsystem at any given frequency is given by the following equation, where M is always a positive number, and represents the amount (in dB) by which the subsystem must be lower in emissions level than the desired emissions level for the entire system.

$$M(\mathrm{dB}) = (10 \log_{10} NS) + E + S + LE + LM \qquad (1)$$

where

- NS = the maximum number of synchronously operated subsystems in one row (lineup) which contains the subsystem under test,
- E = 6 dB measurement error allowance,
- S = 0 to –8 dB building shielding allowance, depending on building characteristics and whether building wall attenuation can be considered as part of the final system,
- LE = 0 or –3 dB if, respectively, the subsystem appears or does not appear in a peripheral position,[12]
- LM = 3 or 0 dB if, respectively, the subsystem appears or does not appear in more than one position.[13]

The margin required for a nonsynchronous subsystem is given by

$$M(\mathrm{dB}) = (5 \log_{10} NN) + E + S + LE + LM \qquad (2)$$

where

- NN = the maximum number of nonsynchronous subsystems in one lineup which contains the subsystem under test, and the other parameters are as previously defined.

6.1.5.2 Allocation method 2

For synchronously operated subsystems the margin required for a subsystem is obtained from

$$M(\mathrm{dB}) = 10 \log_{10} \mathrm{PDR} \qquad (3)$$

where

- PDR is the power dissipation ratio, the power dissipated by the subsystem under test divided by the power dissipation of the entire system.

For the nonsynchronous case the margin required for a subsystem is obtained from

$$M(\mathrm{dB}) = 5 \log_{10} \mathrm{PDR} \qquad (4)$$

with PDR as defined for the synchronous case.

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[12]Subsystems located such that they are directly on the perimeter of the system, i.e., directly illuminate the measuring antenna, contribute directly to the measured emissions. Those subsystems located “internal” to the system periphery are farther from the measuring antenna, and also have intervening subsystems to further attenuate signals reaching the measuring antenna.

[13]Subsystems appearing at multiple positions in the system, whether “interior” or at the periphery, do not have emissions that add linearly.

6.2 Immunity

Electronic devices must frequently operate in the presence of external radio frequency fields. These may be due to

a) Nearby fixed radio transmitters such as those in the broadcast service or those providing point to point service
b) Mobile radio transmitters such as citizens band and mobile radio-telephone units
c) Noncommunication radio frequency radiators such as industrial heating, medical diathermy machines, or digital computers

Many electrical or electronic devices, when sufficiently close to one of such emitters, can experience degradation of performance or malfunction due to resulting interference.

In addition to the continuous type of interference mentioned in the previous paragraph, other sources of interference produce transients and include electrostatic discharge (ESD), electrical fast transient bursts due to suddenly switched (on or off) equipments, and surges on power and other lines due to switching transients and lightning.

Setting immunity guidelines strict enough to always avoid interference is not economically practicable, so the chosen set of guidelines must provide protection for most of the units without causing an undue cost penalty to the many units that may never encounter high radio frequency fields. This parallels the case of radio frequency emission control as discussed in 6.1. As in emission, the immunity coupling mode may occur by direct response to electric or magnetic fields or by conduction of induced or directly coupled signals on connecting leads and power cords.

6.2.1 General performance criteria

Four general performance criteria are specified for equipment immunity. They are based on the manufacturers original performance specifications. These performance levels are widely accepted throughout the world. The performance criteria are as follows:

a) The apparatus shall continue to operate as intended. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer, when the apparatus is used as intended. The performance level may be replaced by a permissible loss of performance. If the minimum performance level or the permissible performance loss is not specified by the manufacturer then either of these may be derived from the product description and documentation and what the user may reasonably expect from the apparatus if used as intended.

b) The apparatus shall continue to operate as intended after the test. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer, when the apparatus is used as intended. The performance level may be replaced by a permissible loss of performance. However, during the test, degradation of performance is allowed. No change of actual operating state or stored data is allowed. If the minimum performance level or the permissible performance loss is not specified by the manufacturer, then either of these may be derived from the product description and documentation and what the user may reasonably expect from the apparatus if used as intended.

c) Temporary loss of function is allowed, provided the loss of function is self-recoverable or can be restored by the operation of the controls.

d) Degradation or loss of function that is not recoverable due to damage to equipments (components) or software or loss of data. Equipments must not become dangerous to the operator or the environment at any time.

6.2.2 Radio frequency immunity limits (general guidelines)

6.2.2.1 Radiated immunity limits

Definitive studies of the percentage of electronic devices in homes or businesses that encounter high radio frequency fields are limited. It is known that radio frequency fields at some locations can be very high, for example, 150 dB(μV/m) (32 V/m) 200 ft away from a 50 kW nondirectional AM broadcast transmitter antenna, 20 m directly in front of an 8 dB gain amateur antenna fed with 1200 W peak effective power, or less than 1 m from a 5 W mobile transmitter. Even higher fields may exist in extreme cases. However, these extreme locations constitute a very small portion of total locations where electronic equipments is used. Probably less than 5% of these locations experience fields greater than 1 V/m. ([B10], [B12], and [B15].) Experience has shown that most electronic equipments can be designed to withstand electromagnetic fields in the order of 1 to 5 V/m with very little increase in production design cost, but that design complexity usually goes up sharply as the immunity level is raised beyond that.

On the basis of this background, it is recommended that the minimum immunity guideline for electronic equipments be placed at 3 V/m (±3 dB) [129.3 μV/m ± 3 dB] for the electric field and an equivalent free-space conversion for the magnetic field (H = E/377 μA/m for E in μV/m), at the front face of the EUT, calibrated in the absence of the EUT, for the entire frequency range (see Figure 5). It is suggested that this limit be applied to as much of the spectrum as possible to account for a continuous mode of immunity response due to the resonance problems caused by variations in lead lengths, lead terminations, and cabinet or device dimensions, but at least in the range of 2 MHz to 1000 MHz. It is to be understood that some devices will encounter higher fields and must be specially modified or shielded to attain interference-free operation. Where equipment is only tested to pass the low (1 V/m) immunity level, the manufacturer should indicate to the purchaser, in some manner, that the equipment may not operate satisfactorily in certain noisy environments. Those devices whose reliable operation at all locations is essential for any reason should be designed for higher immunity levels as required for their application. These devices normally represent a very small proportion of the total population, and a decision to meet the higher immunity levels must be decided on an individual basis. Examples are shown as dotted lines on Figure 5, labeled: “High—10 V/m” and “Severe—X V/m,” respectively.

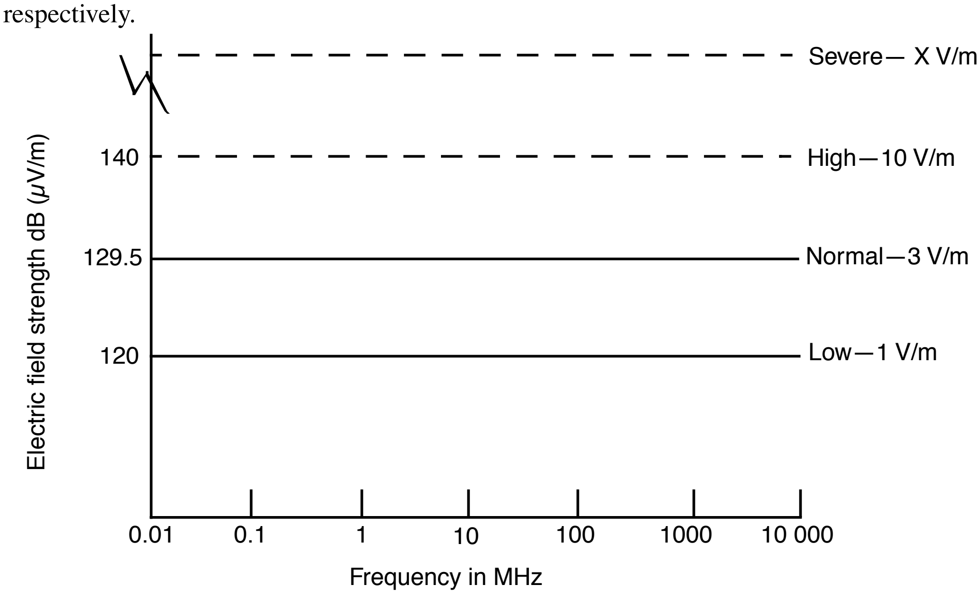

Figure 5—Radiated electric field immunity guidelines.
(Typically the applied field is modulated 80% AM with a 1 kHz sine wave or 100% with a square wave. The levels shown are before modulation is applied.)

6.2.2.2 Conducted immunity limits

Figure 6 shows guideline levels of common-mode conducted immunity. Conducted immunity measurements are considered to be an alternative to radiated measurements so that on overlap in the frequency ranges of test in Figures 5 and 6 is not intended. The transition frequency typically lies between 26 and 80 MHz. Conducted measurements may be made at frequencies up to a maximum of 400 MHz. The level is based on common-mode injection of 3 V signals onto power and interconnecting leads or cables at 150 W impedance. Modulation of 1000 Hz at 80% AM or 100% square wave is to be used. For the test method, see IEC 61000-4-6 (up to 80 MHz) or CS 114 in MIL-STD-462D (up to 400 MHz).

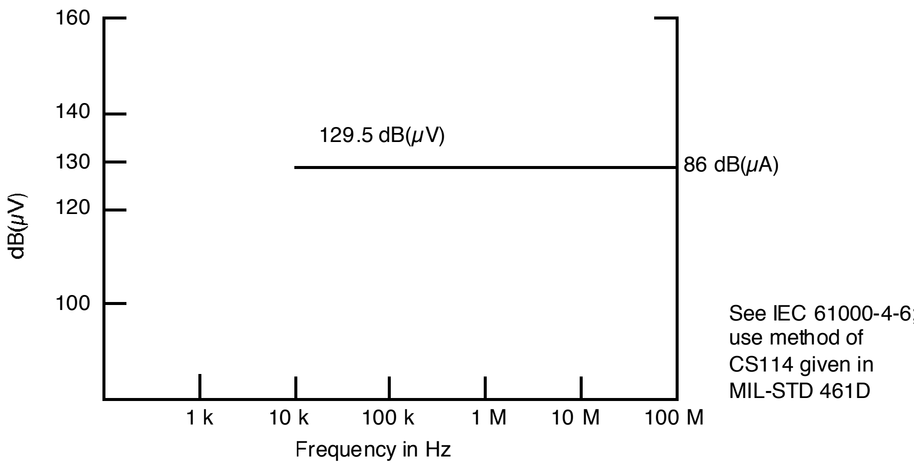

Figure 6—Conducted common-mode injection immunity (before modulation)

6.2.2.3 Fast transient and surge immunity limits

It is desirable to test equipment to determine its ability to withstand high-frequency, short-duration disturbance (chattering relay) bursts. The signals shown in Figure 7, chosen to be representative of powerline transients due to local switching and other inductive events, should be applied to all power and interconnecting leads in a manner that most closely replicates actual exposure conditions. Surges, which have a waveform similar to that shown in Figure 7(c) except that the front and duration times are 1.2 and 50 μs, respectively, appear in the common mode due to external sources such as lightning and distant switching, and differential mode for nearby switching transients. The test is conducted in accordance with IEC 61000-4-4.

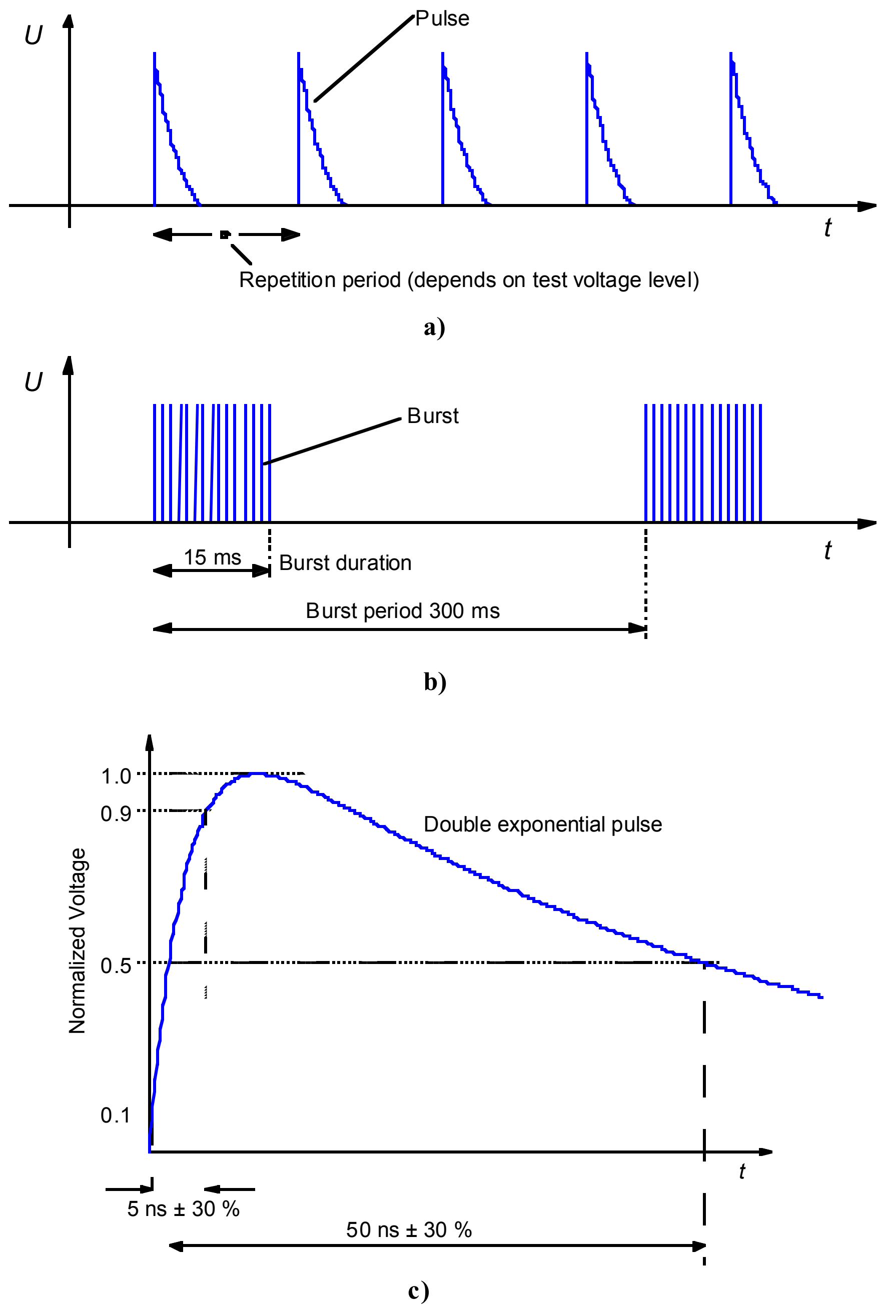

Figure 7—Waveshape of a single pulse into a 50 W load according to IEC 61000-4-4 (see 6.2.2.3)

6.2.2.4 Electrostatic discharge immunity limits

Increasing speed of integrated circuits and reduced physical separation of printed wire board and internal integrated circuit (IC) paths has increased the sensitivity of electronic circuits to ESD. The ESD test is conducted in accordance with IEC 61000-4-2: 1995. It should be used to test all parts of electronic products that might be subjected to ESD by human handling. Where use of a "wrist strap" or other protective device may provide some protection, the requirement may be reduced.

6.2.3 Generic immunity requirements

Sets of requirements that are considered to be generally applicable in cases where there are no special environmental conditions to consider are presented in Table 7. In particular, they apply if there are no specific product requirements and do not conflict with legal requirements. Their adoption by the manufacturer provides the purchaser of the equipment information on its minimum immunity characteristics.

These generic immunity requirements are defined in three categories of environments—residential, industrial, and severe. Covered are—ESD, voltage dips and fluctuations, fast transients (bursts), and radiated and conducted phenomena.

6.2.4 Immunity—requirements for severe environmental conditions

The possibility of a severe environment, i.e., one substantially above that experienced in industrial areas, exists in connection with civilian as well as in military activities. High electromagnetic fields created by radars can impinge on both civilian and military aircraft, and can also appear near radio transmitting antennas located nearby either on land or on ships. Also, high-level transients can appear in power conductors in large switching stations.

The levels given in column 5 of Table 7 are designed to provide general guidance. It must be recognized that the environmental levels given here may be higher than necessary or may be exceeded in particular circumstances.

Table 7—Generic immunity limits

	Frequency of time char.	Limits residential environment	Limits industrial environment	Limits severe environment	Performance degradation criteria[a]	Test method
Radiated H-field[b]	Pulse	—	—	100 A/m	A)	IEC 61000-4-9
Radiated H-field[b]	57 to 63 Hz	3 A/m[c]	30 A/m	—	A)	IEC 61000-4-8
Radiated E-field	N[d] MHz to 2.5 GHz 80% mod.1 kHz	3 V/m[e] (unmod.)	10 V/m[e]	200 V/m	A)	RS103[f] IEC 61000-4-3[g]
ESD	Electrostatic dis-charge	4 kV contact 8 kV air	4 kV contact 8 kV air	6 kV contact 15 kV air	B)	IEC 61000-4-2
Voltage dips[h, i]	1/2 period 6 periods	30% reduction 60% reduction	30% reduction 60% reduction	30% reduction 60% reduction	B) for 1/2 period C) for 6 periods	IEC 61000-4-11
Voltage interruption	300 periods	>95% reduction	>95% reduction	>95% reduction	C)	IEC 61000-4-11
Surge common mode[j]	1.2/50 (8/20) 10/700[k] μs	±2 kV[l]	±4 kV[m]	6 kV	B)	IEC 61000-4-5 C62.45[n]
Surge differential mode[j]	1.2/50 (8/20) μs	±1 kV[l]	±2 kV[m]	3 kV	B)	C62.45[n] IEC 61000-4-5
Fast transients power-port	5/50 ns 5kHz rep rate	±1 kV	±2 kV	2 kV	B)	IEC 61000-4-4
Fast transients signal port	5/50 ns 5kHz rep rate	± 0.5 kV[o]	±2 kV[p]	1 kV[o]	B)	IEC 61000-4-4
Radio frequency common mode, 1 kHz, 80% AM[j]	150 kHz to X MHz[d]	3 V (rms)[e, o] 150 Ω source impedance	10 V (rms)[e, o, q] 150 Ω source impedance	30 V (rms)[e] 150 Ω source impedance	A)	CS114[f] IEC 61000-4-6

Notes to Table 7—

[a] See 6.2.1.

[b] Applicable only to apparatus containing devices susceptible to magnetic fields.

[c] For cathode ray tube devices the requirement is 1 A/m.

[d] N optional between 26 and 80 MHz.

[e] Before modulation is applied.

[f] See MIL-STD-461.

[g] Covers only frequencies between 80 and 1000 MHz. For tests outside this range the test report should contain evidence of the validation of the characteristics of the facility.

[h] Voltage shifts at zero crossing.

[i] Applicable to input ports only; changes in luminance allowed.

[j] Applicable to both power and signal ports.

[k] Applicable to equipments connected to the telecommunications network.

[l] No requirement for signal ports.

[m] For signal lines the value given is reduced by 1/2 and for lines not involved in process control only applies to ports having connected cables with a total length according to the manufacturer's functional specification that may exceed 10 m.

[n] Testing according to C62.45 may be more severe than with 61000-4-5 because of differences in test generator source impedances.

[o] For signal ports, applicable only to ports for which the length of the connected cable according to the manufacturer's specification may exceed 3 m.

[p] For signal ports not involved in process control the value given is reduced by 1/2 and only applies to ports having connected cables with a total length according to the manufacturer's functional specification that may exceed 3 m.

[q] Except for the ITU broadcast frequency band: 47 MHz to 68 MHz where the level shall be 3 V.

Annex A

(informative)

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