

American National Standard Recommended Practice for Electromagnetic Compatibility Limits and Test Levels

C63[®]

Accredited Standards Committee C63[®]—Electromagnetic Compatibility

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Secretariat

Institute of Electrical and Electronics Engineers, Inc.

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Abstract: A rationale and recommendations for developing emission limits and immunity test levels are presented in this recommended practice. These limits and levels are representative of current practice and user needs. Emission limits are specified by national and international standards bodies. Emission limits for the most part are regulated and hence controlled, which is the case in the U.S. and Canada. Such regulatory limits take precedence, even if the limits are different from those considered in this document. For product immunity, while in some parts of the world this is regulated, for the U.S. and Canada, it is not regulated except for some types of safety equipment. In this way, adequate immunity is more a quality aspect of the product because it does not operate in its intended RF environment, the user would deem it of poor design and quality. The immunity test levels described in this document are representative of common levels applied internationally. However, severe environments (in which levels of electromagnetic disturbance are high) require the consideration of applying higher test levels. This consideration is described in this recommended practice. Finally, it should be noted that the entire recommended practice does not contain normative requirements, as such practices remain optional.

Keywords: ambient noise levels, ANSI C63.12, atmospheric noise, electromagnetic compatibility (EMC), emissions, galactic noise, immunity, limits, man-made noise, test levels

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Introduction

This introduction is not part of ANSI C63.12-2015, American National Standard Recommended Practice for Electromagnetic Compatibility Limits and Test Levels.

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. However, severe environments (high levels) require the consideration of applying high test levels, which are described in this recommended practice. Finally, it should be noted that the entire document does not contain normative requirements as such practices remain optional.

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 ANSI 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 1 undertake a first revision, which was published by IEEE in 1988. Further changes in international and military immunity techniques and requirements, as well as requests by potential users of ANSI C63.12, led to the 2007 reaffirmation revision.

C63[®] Subcommittee 3 and the main C63[®] committee believed it was time to fully review the document and come up with additions and changes to bring the 2007 edition in line with current practices. For this edition, the following significant changes were made:

- a) The addition of a more current list of definitions and references, especially those focusing on immunity measurements, that is most useful in understanding ANSI C63.12. The bibliography was also changed with the addition of more current documents.
- b) “Immunity” was substituted for “susceptibility” where statements such as “product was more susceptible” was changed to “product had less immunity,” which has the same meaning. The preferred use of “immunity” matches present international usage in published immunity standards where “susceptible” is not used at all.

NOTE—The U.S. Department of Defense continues to use the term “susceptibility” in their EMC standards, and it is used as the lack of “immunity.”

- c) For more universal applicability, emission limits are identified for Class A and Class B environments and not residential, commercial, light industrial, or industrial. Corresponding examples are given such as typically a Class B environment is residential and a Class A environment is industrial or commercial.
- d) For emission measurements, more reliance is made on the techniques in ANSI C63.4, including reference to antenna calibration methods contained in ANSI C63.5.
- e) Clarification is made on stating emission limits and immunity test levels, as it is up to the user to use test levels for product performance. Emission limits are regulated and thus are not voluntary.
- f) Updated ambient radio noise curves from ITU-R have been added. They cover maximum and minimum of atmospheric noise, galactic noise, and noise in various environments. These include man-made noise at RF quiet sites and in city areas.
- g) Updated the recommended generic immunity test levels.

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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1. Overview

Over the years, electromagnetic compatibility (EMC) measurement and control standards have been developed for use by industry and testing organizations. Many of these standards apply to particular classes of products such as radio/TV receivers, intentional transmitters, and incidental radiation products with internal microprocessors.

1.1 Scope

This recommended practice presents a rationale for developing emission limits and immunity test levels and recommends that these facets are representative of current practice and user needs. Emission limits generally are written by national and international standards bodies. Emission limits for the most part are specified by regulators, which is the case in the U.S. and Canada. Such regulatory limits take precedence, even if the limits are different from those considered in this document. In the U.S. and Canada, product immunity is not regulated except for some safety equipment. In this way, adequate immunity is more a quality aspect of the product as if it does not operate in its intended RF environment, the user would deem it of poor quality. It should be noted that the entire document does not impose normative requirements, but recommends options.

1.2 Purpose

The main purpose of this recommended practice is to aid manufacturers who might need to modify the emissions their products generate (as long as regulatory limits are met) to meet for example intra-system needs for their products. There might also be a need to have different (higher) immunity test levels than what is typically required if the product will be used in severe electromagnetic environments. As the use of electronics is constantly changing (e.g., the Smart Grid [B10]¹), the test methods, immunity test levels, and emission limits likewise need to be periodically reviewed to assure that EMC is maintained. In fact, these EMC considerations might have to be tailored for specific designs and go beyond regulatory requirements to ensure proper product operation at the user location, which is exposed to a myriad of RF environments and where it is likely that there are other electronic products that might suffer interference from RF generated by the product. The emissions and immunity measurement technique used can have an impact on the accuracy, repeatability, and reproducibility of the test results. Emissions from products should be controlled to protect radio services by not causing interference, and at the same time, products should have sufficient immunity to be able to operate as intended in the RF environments expected in locations where the products are intended to be used.

As part of the development of emission limits and immunity test levels, the following topics are discussed in this recommended practice:

- a) The general properties of both man-made and natural environmental electromagnetic noise (disturbances), as this will impact the product immunity test levels and immunity tests that are needed so that a product performs within manufacturer's specifications in the intended use environments
- b) Selection, capabilities, and use of proper emissions measurement instrumentation.
- c) The test instrumentation used to simulate the RF environment to which products are expected to be exposed so that the products work properly with minimal customer EMC complaints.
- d) A defensible rationale that can be used in selecting a consistent set of limits for emissions and test levels for immunity,² subject to good engineering practice and cost-effective EMC management, taking into account any regulatory requirements.

Topic a) through topic d) of this subclause are intended to be applicable to individual products as well as systems of various sizes and, if properly applied, provide guidance for obtaining both intrasystem and intersystem electromagnetic compatibility. This recommended practice assists manufacturers in specifying their own emissions limits (but as a minimum meeting regulatory and user requirements) and test levels as appropriate for their product to function properly and to not cause any undesired interference.

NOTE—Emission limits and immunity test levels along with the necessary measurement techniques described herein are proposed for general use to the extent that they are not covered in regulations or in customer requirements.

2. References

The following references are intended to assist the user of this recommended practice and are listed in this clause because they have direct application to this recommended practice. The information in each of these references as applied in this document is to be considered as informative. For all ASC C63[®] documents referenced in this document, the latest version applies. For non-ASC C63[®] documents with no date, the latest version applies. Regional documents should be consulted for variations from the international standards referenced.

¹ The numbers in brackets correspond to those of the bibliography in Annex A.

² In the past, *susceptibility* was the generally used terminology and was meant to be the opposite of *immunity*.

ANSI C63.2, American National Standard for Electromagnetic Noise and Field Strength Instrumentation, 10 Hz to 40 GHz Specifications.³

ANSI C63.4, 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 C63.5, American National Standard for Electromagnetic Compatibility—Radiated Emission Measurements in Electromagnetic Interference (EMI) Control—Calibration of Antennas (9 kHz to 40 GHz).

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

ANSI C63.9, American National Standard for RF Immunity of Audio Office Equipment to General Use Transmitting Devices With Transmitter Power Levels up to 8 Watts.

ANSI C63.14, American National Standard Dictionary of Electromagnetic Compatibility (EMC) including Electromagnetic Environmental Effects (E3).

ANSI C63.15, American National Standard Recommended Practice for the Immunity Measurement of Electrical and Electronic Equipment.

ANSI C63.16, American National Standard Guide for Electrostatic Discharge Test Methodologies and Criteria for Electronic Equipment.

CISPR 11:2010, Industrial, scientific and medical equipment—Radio-frequency disturbance characteristics—Limits and methods of measurement.⁴

CISPR 13:2009, Sound and television broadcast receivers and associated equipment—Radio disturbance characteristics—Limits and methods of measurement.

CISPR 16-1-2:2014, Specification for radio disturbance and immunity measuring apparatus and methods—Part 1-2: Radio disturbance and immunity measuring apparatus—Ancillary equipment—Conducted disturbances.

CISPR 22:2008, Information technology equipment—Radio disturbance characteristics—Limits and methods of measurement.

CISPR 32:2012 (with COR1:2012 and COR2:2012), Electromagnetic compatibility of multimedia equipment—Emission requirements.

IEC 60050-161, International Electrotechnical Vocabulary (IEV) Chapter 161—Electromagnetic compatibility,^{5,6}

IEC 61000-4-2 Ed. 2.1 (2014-2), Electromagnetic compatibility (EMC)—Part 4-2: Testing and measurement techniques—Electrostatic discharge immunity test.

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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/>). CISPR documents are also available in the United States from the American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

⁵ Chapter 161 from International Electrotechnical Vocabulary is available from the IEC Website at <http://www.electropedia.org/iev/iev.nsf/index?openform&part=161>.

⁶ IEC publications are available from 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 American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

IEC 61000-4-3:2010, Electromagnetic compatibility (EMC)—Part 4-3: Testing and measurement techniques—Radiated, radio-frequency, electromagnetic field immunity test.

IEC 61000-4-4:2012, Electromagnetic compatibility (EMC)—Part 4-4: Testing and measurement techniques—Electrical fast transient/burst immunity test.

IEC 61000-4-5:2005 (with COR1:2009), Electromagnetic compatibility (EMC)—Part 4-5: Testing and measurement techniques—Surge immunity test.

IEC 61000-4-6:2008, Electromagnetic compatibility (EMC)—Part 4-6: Testing and measurement techniques—Immunity to conducted disturbances, induced by radio-frequency fields.

IEC 61000-4-8:2009, Electromagnetic compatibility (EMC)—Part 4-8: Testing and measurement techniques—Power frequency magnetic field immunity test.

IEC 61000-4-9:2001, Electromagnetic compatibility (EMC)—Part 4-9: Testing and measurement techniques—Pulse magnetic field immunity test.

IEC 61000-4-10:2001, Electromagnetic compatibility (EMC)—Part 4-10: Testing and measurement techniques—Damped oscillatory magnetic field immunity test.

IEC 61000-4-11:2004, Electromagnetic compatibility (EMC)—Part 4-11: Testing and measurement techniques—Voltage dips, short interruptions and voltage variations immunity tests.

IEC 61000-4-12:2006, Electromagnetic compatibility (EMC)—Part 4-12: Testing and measurement techniques—Ring wave immunity test.

IEC 61000-4-13:2002+AMD1:2009, Electromagnetic compatibility (EMC)—Part 4-13: Testing and measurement techniques—Harmonics and interharmonics including mains signaling at a.c. power port, low frequency immunity tests.

IEC 61000-4-16:2011, Electromagnetic compatibility (EMC)—Part 4-16: Testing and measurement techniques—Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz.

IEC TR 61000-2-5:2011, Electromagnetic compatibility (EMC)—Part 2-5: Environment—Description and classification of electromagnetic environments.

IEEE Std 473TM-1985 (withdrawn), IEEE Recommended Practice for an Electromagnetic Site Survey (10 Hz to 10 GHz).^{7 8 9}

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

IEEE Std C62.45TM-2002, IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V or Less) AC Power Circuits.

ITU-R Recommendation P.372-11 (09/2013), Radio noise (replacement document for CCIR R322).¹⁰

⁷ IEEE Std 473-1985 has been withdrawn; however, copies can be obtained from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

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¹⁰ ITU-T publications are available from the International Telecommunications Union, Place des Nations, CH-1211, Geneva 20, Switzerland/Suisse (<http://www.itu.int/>).

MIL-STD-461F, 10 December 2007, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, U.S. Department of Defense.¹¹

U.S. Code of Federal Regulations, Title 47 Part 15 (47 CFR 15), Telecommunication—Radio Frequency Devices.¹²

U.S. Code of Federal Regulations, Title 47 Part 18 (47 CFR 18), Telecommunication—Industrial, Scientific, and Medical Equipment.

U.S. Code of Federal Regulations, Title 47 Part 68 (47 CFR 68), Telecommunication—Connection of Terminal Equipment to the Telephone Network.

3. Definitions and acronyms

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. Additional definitions are included in ANSI C63.14.¹³ The EMC Collection Definitions from the *IEEE Standards Dictionary* and EMC Chapter 161 of IEC 60050, the International Electrotechnical Vocabulary (IEV), should be consulted for terms not defined in this clause or in ANSI C63.14.¹⁴

ambient level (electromagnetic): The values of radiated and conducted signal and noise existing at a specified test location and time when the test sample is not activated. (*IEEE Standards Dictionary*)

NOTE—For example, atmospheric noise and signals from man-made and other natural sources all contribute to the ambient level.¹⁵

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 time.

atmospheric noise: Electromagnetic emissions in the radio frequency range having their sources in natural atmospheric phenomena.

electromagnetic disturbance: Any electromagnetic phenomenon that may degrade the performance of a device, equipment or system or adversely affect living or inert matter. (IEC 60050-161-01-05)

NOTE—An electromagnetic disturbance may be an electromagnetic noise, an unwanted signal or a change in the propagation medium itself.

electromagnetic interference (EMI): Degradation of the performance of an equipment, transmission channel or system caused by an electromagnetic disturbance. (IEC 60050-161-01-06)

NOTE—In English, the terms “electromagnetic disturbance” and “electromagnetic interference” designate respectively the cause and the effect, but are often used indiscriminately.

¹¹ MIL publications are available from DLA Document Services, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, USA (<https://assist.dla.mil/>).

¹² U.S. Code of Federal Regulations are available from the U.S. Government Publishing Office, P.O. Box 979050, St. Louis, MO 63197-9000, USA (<http://www.ecfr.gov/>).

¹³ Information on references can be found in Clause 2.

¹⁴ The *IEEE Standards Dictionary Online* is available from the IEEE Standards Association at <http://ieeexplore.ieee.org/xpls/dictionary.jsp>.

¹⁵ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

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

emission: A signal radiated or conducted, the presence of which is intentional or unintentional, and may be continuous, momentary or intermittent.

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

external noise factor: $F_a = 10 \log f_a$ dB where $f_a = p_n/k t_0 b$

where

p_n is the available noise power from an equivalent lossless antenna
 k is the Boltzmann's constant (1.38×10^{-23} J/K)
 t_0 is the reference temperature (K) taken as 290 K
 b is the noise power bandwidth of the receiving system (hertz)

[ITU-R Recommendation P.372-11 (09/2013)]

galactic noise: *see natural noise.*

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

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.

man-made noise (emissions): Electromagnetic noise having its source in man-made devices. (Adapted from IEC Chapter 702-08-12)

micropulsations (geomagnetic micropulsations): Short duration, low frequency changes in the magnetic field surrounding the earth.

natural noise: Electromagnetic noise having its source in natural phenomena and not generated by man-made devices. (IEC Chapter 702-08-11)

noise amplitude distribution (NAD): A distribution showing the pulse amplitude that is equaled or exceeded as a function of pulse repetition rate. (Furutsu et al. [B11])

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.

3.2 Acronyms

AE	auxiliary or associated equipment
AM	amplitude modulation
ANSI	American National Standards Institute
APD	amplitude probability distribution
CCIR	International Radio Consultative Committee (now part of ITU as ITU-R)
CFR	Code of Federal Regulations

CISPR	Special International Committee on Radio Interference
CW	continuous wave
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EMP	electromagnetic pulse
ESD	electrostatic discharge
FCC	Federal Communications Commission
FFT	Fast Fourier Transform
FM	frequency modulation
HF	high frequency
IC	integrated circuit
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IEEE-SA	Institute of Electrical and Electronic Engineers – Standards Association
IRE	Institute of Radio Engineers
ISBN	International Standard Book Number
ISM	Industrial, Medical, Scientific
ITU	International Telecommunications Union
ITU-R	International Telecommunications Union – Radio
LISN	line impedance stabilization network
MIL-STD	Military Standard (USA)
NAD	noise amplitude distribution
QP	quasi-peak
RF	radio frequency
RMS or rms	root mean square
RTCA	Radio Technical Commission for Aeronautics
TCM	total common mode
TV	television
URSI	International Union of Radio Science

4. Description of environmental RF emissions

The minimum level required for satisfactory receiver reception of desired radiated RF signals is determined in part by the level of environmental RF emissions or undesired signals with which the desired signal must compete with a needed signal-to-noise ratio. If a wanted and unwanted signal are closely spaced in frequency and thus fall into the passband of the receiving device, proper signal reception may not be possible. Several types of RF emissions can influence reception and equipment operation; however, with a particular system and environment, one emission type will generally dominate at a given time, especially if the receiving equipment is located physically near a specific source. Unintentional “receivers” (e.g., information technology equipment) are also subject to interference.

Sources of RF emissions usually are divided into two general groups, those emitting broadband and those emitting narrowband noise. The distinction is based on comparison of the emission spectrum with the bandwidth of the measurement instrument used. Broadband noise is frequently impulsive and can be divided further into two groups, natural and man-made. Narrowband noise is usually generated by a variety of restricted radiating devices. These include industrial, scientific, and medical (ISM) equipment, licensed and unlicensed (e.g., 47 CFR 15) radio transmitters, and digital devices that emit line spectra at harmonics of the clock frequency. Regulated radiating devices generally emit RF energy over a limited portion of the spectrum, clustered around discrete frequencies. Licensed and unlicensed radio transmitters radiate a spectrum near their carrier frequency. The continuing proliferation of low-power portable transmitting

sources has increased the need for consideration of the immunity of electronic systems that must operate satisfactorily in close proximity to these sources.

To the extent that RF emissions vary, a time-domain statistical description is necessary. 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 systems with which it might interfere. For many man-made sources, the noise can be characterized as stationary, whereas for natural sources, the noise can occur with variations having time periods ranging from fractions of a second to a year or more.

5. Measurement of RF emissions (radio noise)

5.1 Introduction

In determining how to perform measurements of RF emission sources, the following parameters should be kept in mind (see IEEE Std 473-1985):

- a) Simple to measure and analyze
- b) Such that the interference effect of the noise on the various types of electronic devices or systems likely to be affected can be evaluated
- c) Such that they can be related to groups of emitters
- d) Useful in identifying the source of the measured noise

Instrumentation and measurement methods used for determining equipment emission characteristics are described in detail in ANSI C63.2 and ANSI C63.4, respectively. ANSI C63.5 provides techniques for emission measurement antenna calibration. These documents should be reviewed before proceeding to make emissions measurements. In particular, measurement of RF emissions as described in ANSI C63.4 relates to measurement of emissions from specific devices in a controlled manner at a test facility. This is quite different from measuring ambient noise, as such noise is emitted from many sources, rather than one under test. As might be expected, there is much more control and repeatability in measuring a device than the general RF ambient. To promote repeatability and reproducibility, ANSI C63.4 has specific test setups and procedures and can be used to find the maximum emissions. For conducted emissions, the maximum is found primarily by varying the modes of operation of the device. For radiated emissions, it is much more complex, where a receiving antenna is elevated between 1 m and 4 m to find the point of the in-phase addition of the direct and the indirect reflection as the device is rotated on a turntable. Above 1 GHz, ground plane reflection has little effect. However, in most cases the radiation pattern of devices become more directional. In addition, the antennas used in this frequency range may exhibit directional patterns. Therefore, a height scan and aiming of the receiving antenna are also required to properly measure the maximum emissions of a device under test.

5.2 Selection of parameters

The measurement of radiated RF signals emitted by multiple devices or radio transmitters is addressed in IEEE Std 473-1985. ANSI C63.4 is focused on emission measurements of individual devices in a controlled environment. This standard addresses radiated and conducted emission measurements, both of which are of importance in the limit-setting process.

5.2.1 General

No single parameter can be selected as the best for measuring interference effects on a wide variety of services, e.g., voice, facsimile, analog data, digital data, and television (TV). There is also a wide range of required 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 for AM radio 100% of the time. Otherwise, a measure related to the average or rms level might be more appropriate.

5.2.2 Radio systems interference

Generally, radio communication receiving systems will have the greatest sensitivity to RF emissions as these systems contain circuits that are usually much more sensitive than circuits used for local (wired) communications and control purposes. Furthermore, there have been efforts, 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. Interference (or severe fading) tends to occur over limited periods of time and frequently is capable of blocking reception of any signal, however coded. This has led to the consideration of redundancy 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 affects the choice of noise measurement parameters.

The interference produced by an undesired continuous wave (CW) signal depends 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.¹⁶ 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, frequency offsets of 10 kHz or 20 kHz are used for television stations. Impulsive interference having certain repetition rates can prove especially disruptive to TV reception. The design of the TV receiver synchronization circuit is critical in minimizing interference.

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

Thus, the critical levels of particular forms of a disturbance can be dependent on the design of the receiving systems. The recommendations in this recommended practice are based on the more common systems used in broadcast and point-to-point communications.

5.2.3 Non-radio systems interference

Non-radio systems include control, local data transfer systems, and other electronic equipment. Such systems operate at higher signal levels than radio systems (other than commercial broadcast transmitters) and therefore usually may 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) can be quite capable of interfering with control, local data transfer systems, and other electronic equipment at the same time.

5.3 Measurement instrumentation detectors

5.3.1 General

Measurement instrumentation includes both receivers and spectrum analyzers. Detectors, such as the quasi-peak, peak, root-mean-square (rms), and average detectors, can be used to measure certain characteristics of emissions [B4], [B15]. One or more of the detectors can be used to predict the effects of measured emissions on the performance of a specific electronic system, provided the repetition rate, bandwidths of both the measuring system and system under test, and other vital information, e.g., the actual signal characteristics (narrowband or broadband), are known.

¹⁶ In the most common application, two signals at frequencies f_1 and f_2 are mixed, creating two new signals, one at the sum $f_1 + f_2$ of the two frequencies, and the other at the difference $f_1 - f_2$. These new frequencies are called heterodynes. Typically only one of the new frequencies is desired, and the other signal is filtered out from the output of the mixer. Heterodyne frequencies are closely related to the phenomenon of beats in acoustics.

NOTE—The Fast Fourier Transform (FFT) methodology uses the same detectors.

5.3.2 Quasi-peak detector

The implementation of the quasi-peak detector, as specified in CISPR 16-1-1 and ANSI C63.2, consists of a circuit with a different charge, discharge, and meter constant, depending on the measurement frequency range. This detector weights broadband signals as a function of repetition rate. Lower repetition rate emissions cause a lower annoyance factor and thus get less emphasis. Higher repetition rate signals cause more annoyance in broadcast systems and are emphasized more by the quasi-peak detector. As the repetition rate approaches that of a CW signal (i.e., 100% duty cycle), it reaches the maximum interference potential and therefore no weighting is applied at all, which results in the maximum level at the detector output. The quasi-peak detector circuit also includes a network that simulates an analog meter movement. This time constant provides a smoothing function to the signal at the output of the previous detector stages so that a single value can be measured. The quasi-peak value will always be less than or equal to the peak value of the emission measured.

5.3.3 Peak detector

Initial EMI measurements (i.e., pre-scans) are usually made using the peak detector. This detection mode is much faster than quasi-peak detection, which is required for some final measurements. Because signals measured in peak detection mode always have amplitude values equal to or greater than quasi-peak or average detection modes, it is very efficient to take a sweep and compare the results to a limit line.

The peak-measuring instrument has an envelope or peak detector in its IF section with a time constant that allows the voltage at the detector output to follow the peak value of the IF signal at all times. In other words, the detector can follow the fastest possible change in the envelope of the IF signal.

5.3.4 RMS detector

The rms detector is used in the measurement of random noise. It has the advantage that its output can be related to the spectral power density, which, for noise with a flat spectrum envelope, is independent of the measurement bandwidth. For some types of transmission, it can be correlated quite well with the interference effect. Because the response of an rms measuring instrument is proportional to the square root of the bandwidth for any type of broadband disturbance, the actual bandwidth need not be specified. For such broadband disturbance, the measurement result may be quoted as that “in 1 kHz bandwidth,” by dividing the measured value by the square root of the power bandwidth given in kilohertz. However, the actual value of the bandwidth should be stated when the disturbance level is reported.

5.3.5 Average detector

The average detector is used for measurements of narrowband signals to overcome problems associated with either modulation content or the presence of broadband noise. This detector strips the modulation content from narrowband signals and suppresses the broadband signal content in the spectrum of interest in order to measure the amplitude of the remaining carriers. Its purpose is to recover the amplitude of any narrowband signal that might be buried in broadband signals like pulses or a modulation envelope. Average detection is based on empirical evidence that has shown that combined narrowband and broadband signals can cause more annoying interference than would be indicated by a quasi-peak measurement alone. The quasi-peak detector responds predominantly to the peaks of a broadband impulsive signal. Therefore, the pulses can mask a lower amplitude continuous sine wave signal. The characteristics of the average detector, on the other hand, very effectively suppress broadband impulsive signals and recover the amplitude of the underlying sine wave or narrowband signal.

5.4 Statistical measures

Reference books such as *Introduction to Statistical Communication Theory* [B17], *Man-Made Radio Noise* [B21], and *Measuring the Radio Frequency Environment* [B22] 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 (e.g., Gaussian, atmospheric, and man-made), performance can be determined for most systems from the amplitude probability distributions (APDs) of the disturbances and of the signal envelopes [B1], [B6]. In addition, the noise amplitude distribution (NAD) has been measured frequently. Both distributions give 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, because some forms of additive interference are correlated in time, higher order distributions are, in principle, also required for some systems. References [B2], [B5], [B13], [B20], [B23], and [B28] give specific examples of such studies for digital systems, while references [B19], [B21], [B26], [B27], and [B29] and their bibliographies address 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 might be required.

5.5 Effect of measurement bandwidth

Specific resolution bandwidths are specified in CISPR 16-1-1 and ANSI C63.2 for measurements in different frequency ranges. In general, EMI receiver or spectrum analyzer IF filters are usually specified by a bandwidth (e.g., 6 dB or 3 dB bandwidth) and additional information about its frequency response, which can either be the shape factor of the filter (e.g., ratio 60 dB to 3 dB bandwidth) or a mask that the frequency response has to fit. CISPR 16-1-1 references the 6 dB bandwidth values of four IF filters to be used in the frequency range of 9 kHz to 18 GHz as indicated in the following list:

- 200 Hz (for 9 kHz to 150 kHz)
- 9 kHz (for 150 kHz to 30 MHz)
- 120 kHz (for 30 MHz to 1 GHz)
- 1 MHz (for 1 GHz to 18 GHz)

Furthermore, for each of these filters, a mask is specified showing the insertion loss versus frequency offset from the filter's center frequency. Certain tolerances are allowed that can impact the measurement result of broadband signals, especially when peak detection is used.

6. Limit and test level setting

6.1 General

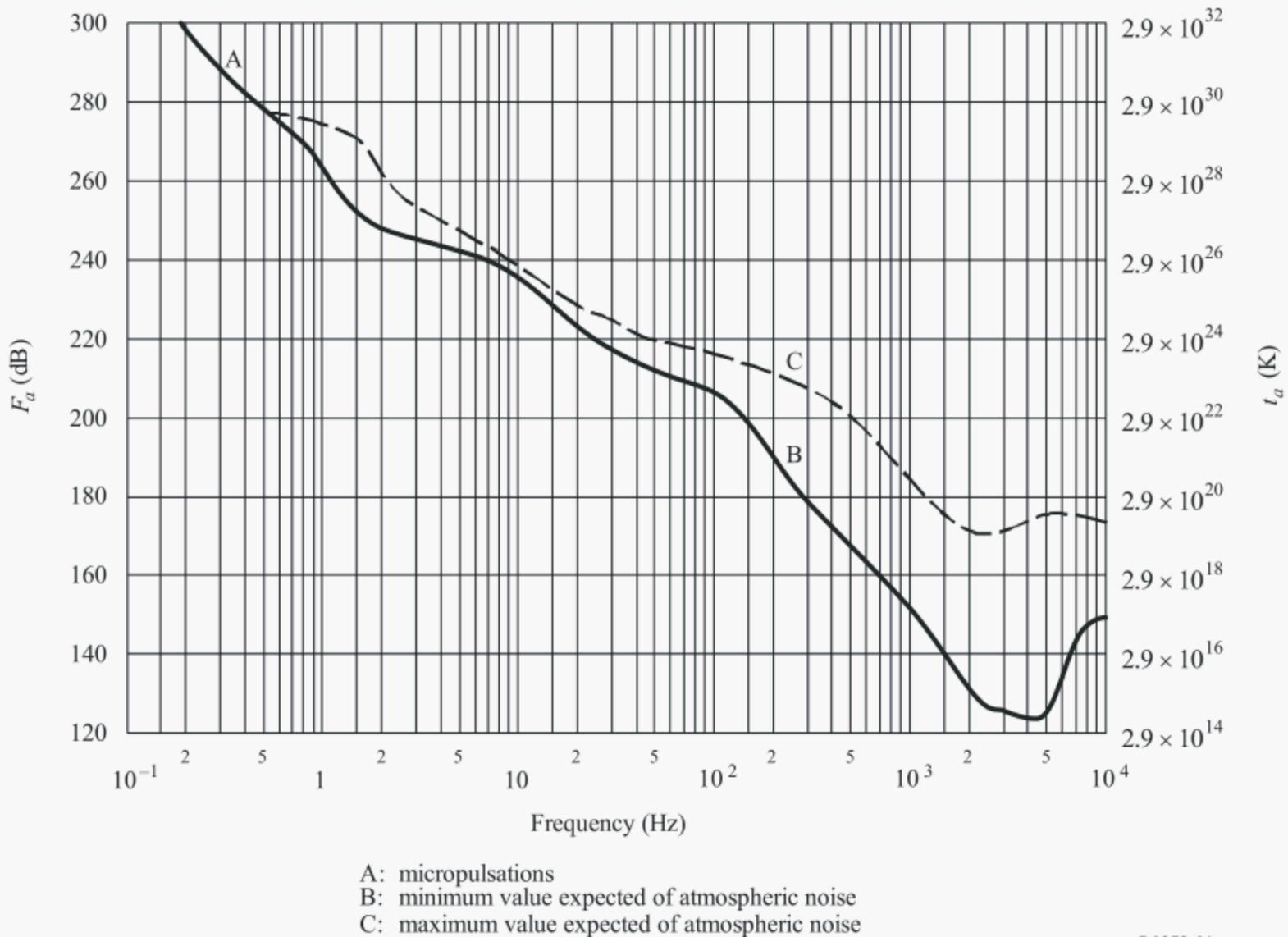
IEC TR 61000-2-5:2011 provides fundamental concepts related to the EMC environment, classes of operation, and estimated levels of various types of electromagnetic disturbances in various electromagnetic environments. Clause 6 further develops the rationale for, and suggests guidelines for, the setting of permitted levels of electromagnetic emissions from various types of unintentional radiators. It also provides guidelines for setting immunity test levels. A basis for establishing general interference/emission objectives is first developed, followed by examples of derivation of test specifications for specific equipment 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 or test levels supersede limits recommended herein. For use in environments containing especially sensitive receivers or in severe environments such as experienced in military applications, special limits or test levels might be required.

6.2 Emissions (protection of radio reception)

6.2.1 General

Interference with a radio or other equipment under test is a function of the magnitude of electromagnetic disturbances and characteristics of the RF receiver (system or equipment under test that is potentially not immune). For economic reasons, the energy used in radio transmission is normally the minimum required to achieve useful communications. This energy is a function of the ambient noise level at the location of the receiver, which must include both natural (atmospheric) and man-made noise. Furthermore, the man-made noise includes RF emissions from both intentional radiators (e.g., broadcast transmitters) and unintentional radiators (e.g., clock harmonics, power transmission lines)

Figure 1, Figure 2, and Figure 3 show the typical median outdoor values of natural and man-made noise (expressed in terms of external noise figure F_a in decibels above kTB . In this expression, k is the Boltzmann constant, T is 290° kelvin, and B is the receiver bandwidth in hertz) (see ITU-R Recommendation P.372-11 (09/2013) and IEEE Std 473-1985).



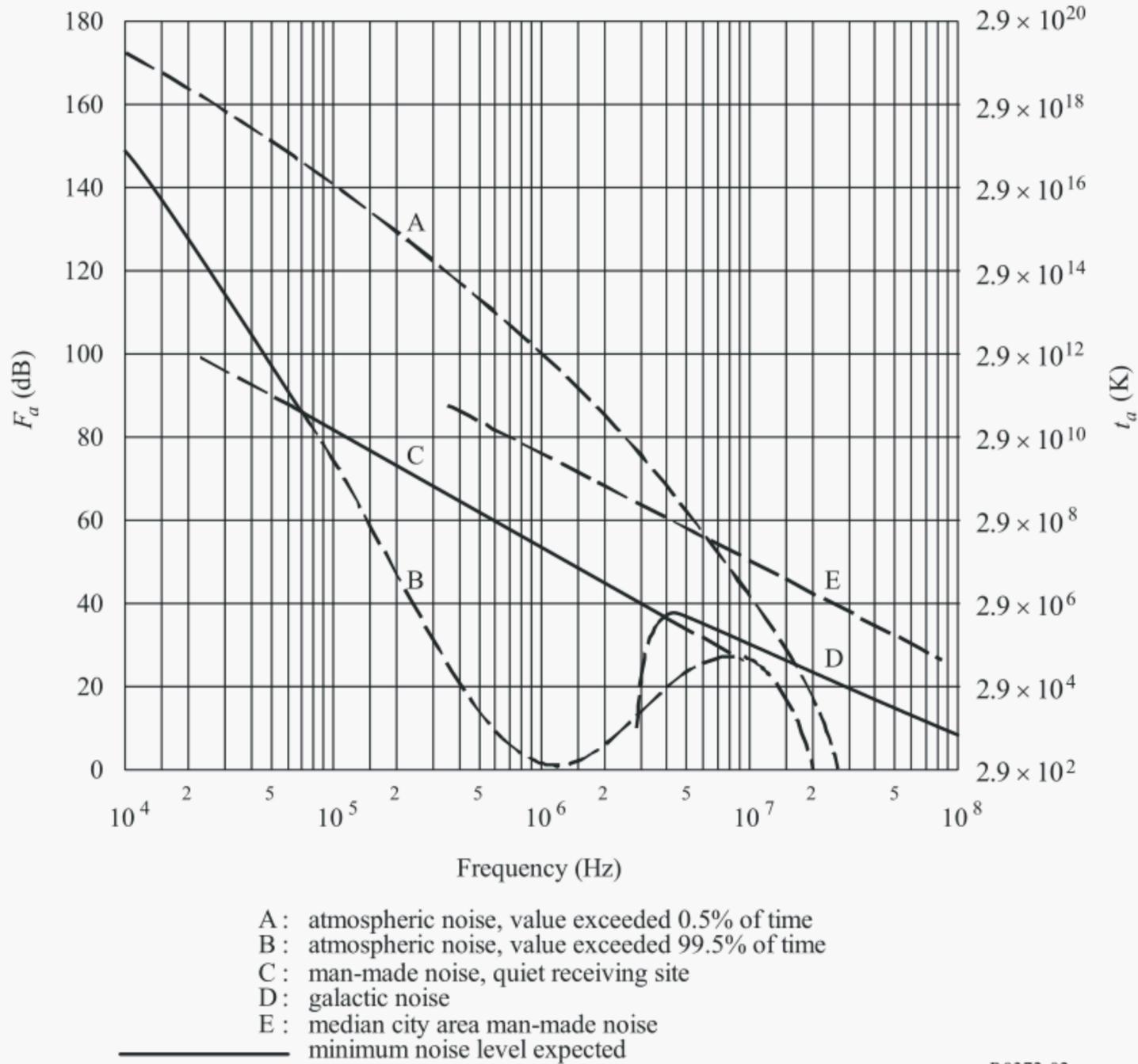
P.0372-01

where t_a is given in degrees kelvin

Figure 1— F_a minimum and maximum versus frequency (10^{-1} Hz to 10^4 Hz)

Although broadband noise is accurately described by the power spectral density as shown in Figure 1, Figure 2, and Figure 3, it is more common to specify limits on radiated noise in terms of electric field strength (see 6.2.4.1 regarding extrapolation) as measured over a specified bandwidth. The 10 kHz bandwidth is taken as typical of AM broadcast receivers in particular. FM communication systems typically use 2.5 kHz to 5 kHz bandwidth. 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.

Figure 2 and Figure 3 show noise curves for quiet areas. The presence of even a small number of automobiles, power lines, or business or residential machines would change the environmental conditions from those of the quiet area curves. The median of the ambient noise is fairly constant in the range of 5 dB to 25 dB ($\mu\text{V}/\text{m}$) at higher frequencies as result of man-made noise and increases at frequencies below about 2 MHz as a result of atmospheric noise [B1], [B3], [B6], [B7], [B12], [B14], [B16], [B24], [B25].



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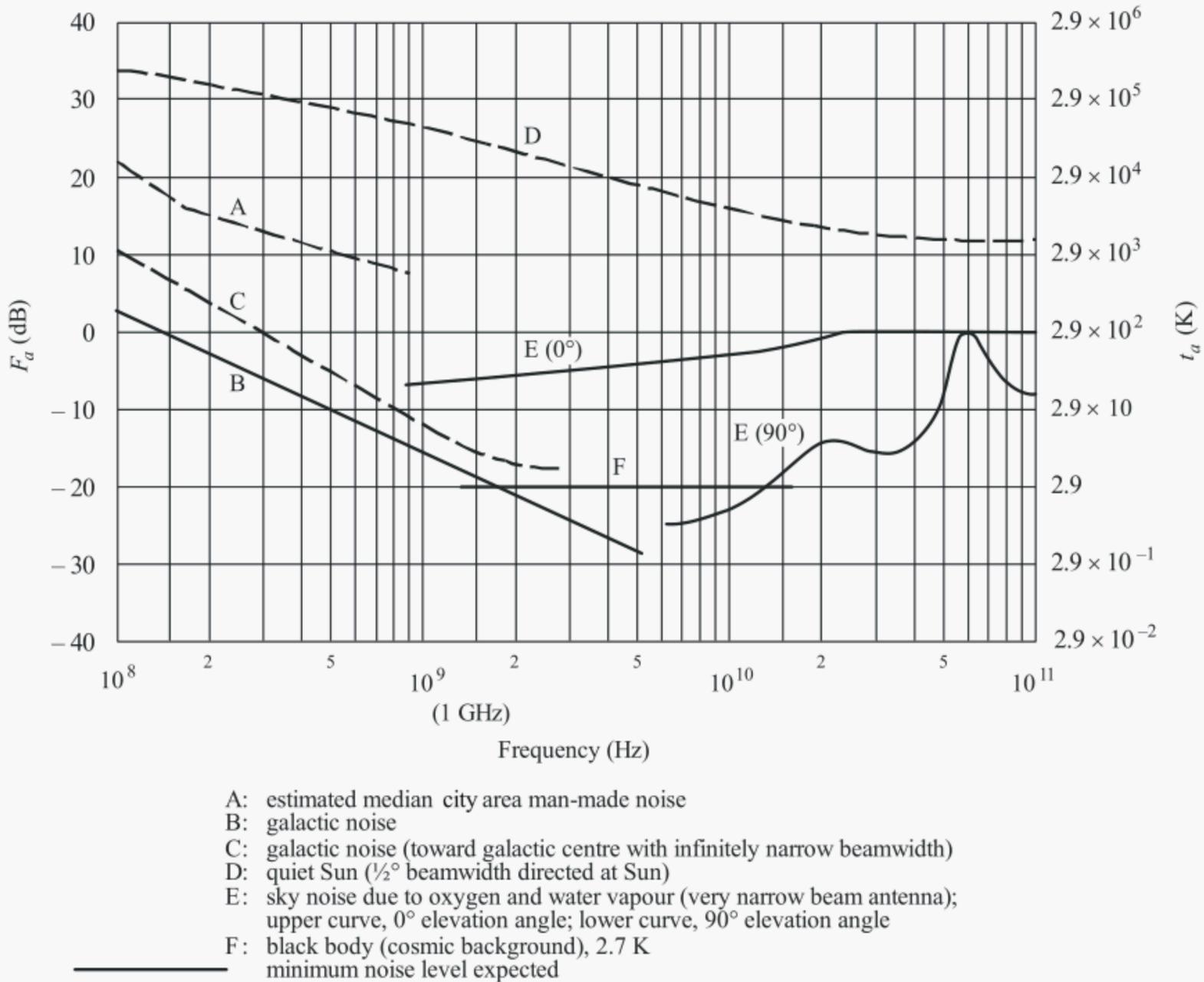
where t_a is given in degrees kelvin

Figure 2— F_a versus frequency (10^4 Hz to 10^8 Hz)

Particular values to be used for guidelines to meet noninterference objectives are not amenable to exact analysis. Data are not available describing the relationship between a given emission limit and the number of interference cases observed or of the impact of various levels of emission 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 equipment used in a residential (Class B) environment and the other for equipment used in an industrial (Class A) environment, has the potential for reducing costs while still providing adequate radio protection and further meets regulatory requirements throughout much of the world. Thus, one set of limits applies to equipment used in a Class A 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 equipment that will be operated in a Class B environment, where noise levels

tend to be lower and where there are generally larger numbers of sensitive receivers. Note that there might be equipment that meets the Class A limit yet is located in a Class B environment. An example of this is the location of a telephone switching center in a residential area. In this case, where there is property surrounding the center, there is generally significant separation between the switch and sensitive receivers to provide an adequate protection distance.



P.0372-03

where t_a is given in degrees kelvin

Figure 3— F_a versus frequency (10^8 Hz to 10^{11} Hz)

There are two other distances that are considered in determining the separation between the EUT and the measuring antenna and the point where limits are referenced. The first is called the measurement distance. This distance could reasonably vary from as little as one meter to as much as several tens of meters away from the EUT. The main concern is that there are inaccuracies when measurements are made too close to the EUT. The inaccuracies are caused by measuring in the near-field region of the source, which in general is not where or how the emission limits are specified. At distances much in excess of 30 m, the levels of EUT emissions that will meet the imposed limits will, in many cases, be lower than the ambient noise level and hence cannot be accurately measured.

The second distance is associated with the separation distance from the EUT, where emission limits are imposed or regulated. This is called the limit distance. When the measurement distance is at the limit distance, then there is no need to extrapolate emission results. In most cases, the limit distance is set at 3 m or 10 m away from the EUT; hence, either of these distances is preferred for particular applications. The

3 m limit distance is most used for Class B measurements and for measurements above 1 GHz. The 10 m limit distance is preferred for Class A measurements. Measurement distances that are less than the limit distance, e.g., measurements made at 3 m when the limit distance is 10 m, are not preferred but might be the only way to measure low emission levels. If this must be done, the measurement results have to be carefully extrapolated to the limit distance. Extrapolation is discussed in 6.2.4.

Emission measurements should be made in accordance with ANSI C63.4, ANSI C63.7, IEEE Std 473-1985, 47 CFR 15 B, CISPR 13:2009, CISPR 22:2008, and CISPR 32:2012. These documents give information on recommended emission test site characteristics and measurement procedures.

Equipment manufacturers and users are advised to refer to any appropriate standards that might apply to their particular types of equipment. ISM RF equipment limits are specified in 47 CFR 18 and CISPR 11:2010. Stricter emission limits might be required for special situations such as onboard aircraft [B8] or for military applications (MIL-STD-461).

6.2.2 Noise levels as a function of frequency

The remaining paragraphs in this subclause and Figure 1, Figure 2, and Figure 3 are based on ITU-R Recommendation P.372-11 (09/2013), Radio noise. In Figure 2, the solid line representing the “minimum noise level expected” is a composite of portions of curves B, C, and D. In Figure 3, the solid line representing the “minimum noise level expected” is a composite of portions of curves B, F, and E.

Figure 1, Figure 2, and Figure 3 and related discussion specify the expected values of “external noise figure” (F_a) in the frequency range 0.1 Hz to 100 GHz for common noise types.

Figure 1 covers the frequency range from 0.1 Hz to 10 kHz. The solid curve is the minimum expected hourly median values of F_a , which is based on measurements (taking into account the entire Earth’s surface, all seasons and times of day), and the dashed curve gives the maximum expected values. In this frequency range, there is very little seasonal, diurnal, or geographic variation. The larger variability in the 100 Hz to 10 000 Hz range is due to the variability of the Earth-ionosphere waveguide cutoff.

Figure 2 covers the frequency range of 10^4 Hz to 10^8 Hz, (10 kHz to 100 MHz) for various categories of noise. The minimum expected noise is shown by the solid curves. For atmospheric noise, the minimum values of the hourly medians expected are taken to be those values exceeded 99.5% of the hours and the maximum values are those exceeded 0.5% of the hours. For the atmospheric noise curves, all times of day, seasons, and the entire Earth’s surface have been taken into account.

Figure 3 covers the frequency range 10^8 Hz to 10^{11} Hz (100 MHz to 100 GHz). Again, the minimum noise is shown by solid curves, while other noise curves are shown by dashed curves.

The majority of the results shown in Figure 1, Figure 2, and Figure 3 are for omnidirectional antennas (except as noted in the figures). For directional antennas, however, studies have indicated, for example, that at HF for atmospheric noise from lightning for very narrowbeam antennas, there can be as much as 10 dB variation (5 dB above to 5 dB below the average F_a value shown), depending on the antenna pointing direction, frequency, and geographical location.

For galactic noise, the average value (over the entire sky) is given by the solid curve labelled galactic noise (Figure 2 and Figure 3). Measurements indicate a ± 2 dB variation about this curve, neglecting ionospheric shielding. The minimum galactic noise (narrowbeam antenna towards galactic pole) is 3 dB below the galactic noise solid curve shown in Figure 3. The maximum galactic noise for narrowbeam antennas is shown by a dashed curve in Figure 3.

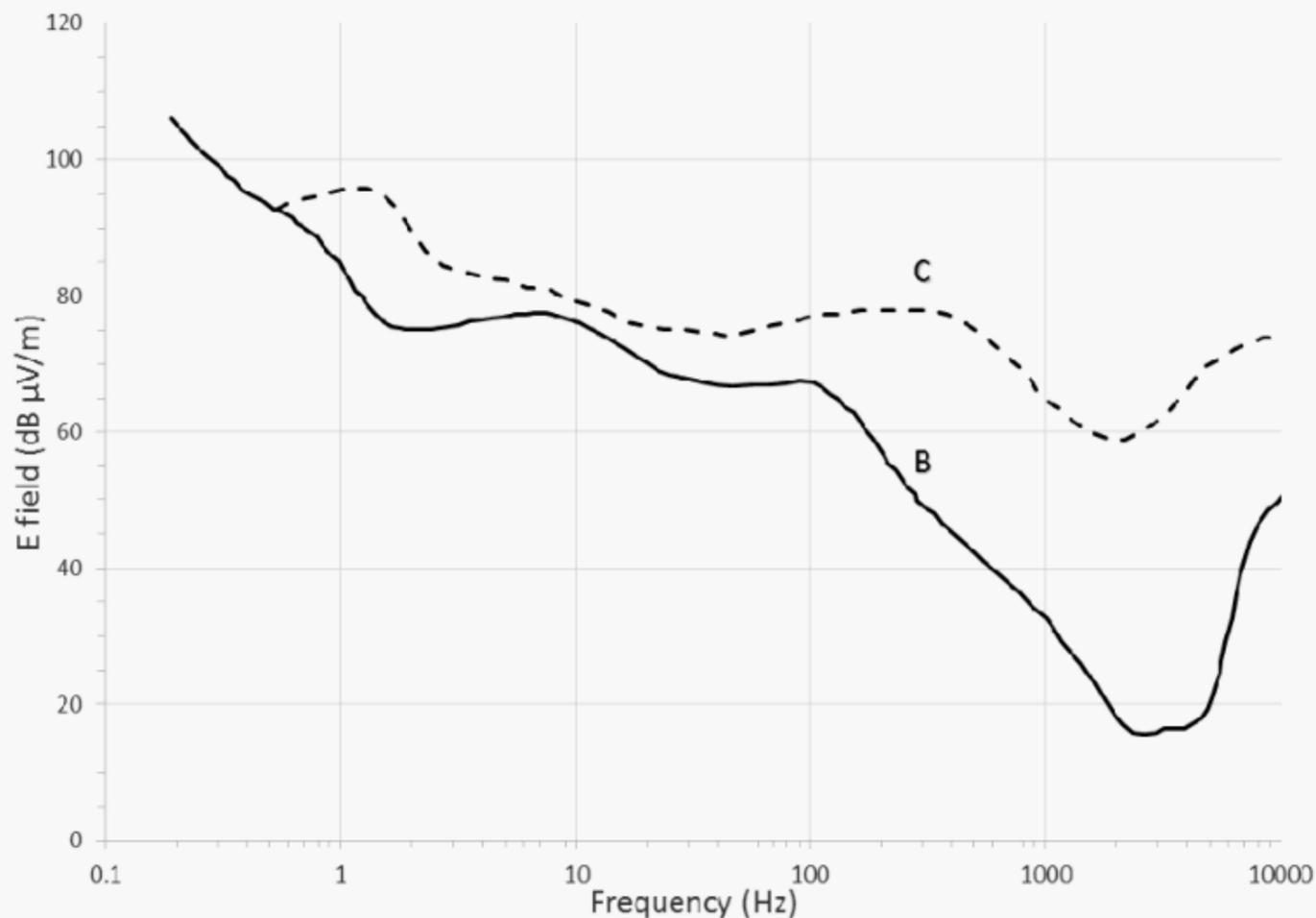
6.2.3 Noise from atmospheric gases and the Earth's surface

Noise from individual sources such as the sun, atmospheric gases, and the Earth's surface is usually identified in terms of a brightness temperature, t_b . The antenna temperature, t_a , is the convolution of the antenna pattern and the brightness temperature of the sky and ground. For antennas with patterns that encompass a single source, the antenna temperature and brightness temperature are the same (e.g., curves C, D, and E of Figure 3). Figure 1, Figure 2, and Figure 3 were converted to E-field strength at 10 kHz bandwidth using Equation (1) for a half-wave dipole in free space from ITU-R Recommendation P.372-11 (09/2013). The results are shown in Figure 4, Figure 5, and Figure 6. (Note that the "minimum noise level expected" line was not converted in Figure 5 and Figure 6 from the respective lines in Figure 2 and Figure 3.)

$$E_n = F_a + 20 \log f_{\text{MHz}} + B - 99 \text{ dB}(\mu\text{V}/\text{m}) \quad (1)$$

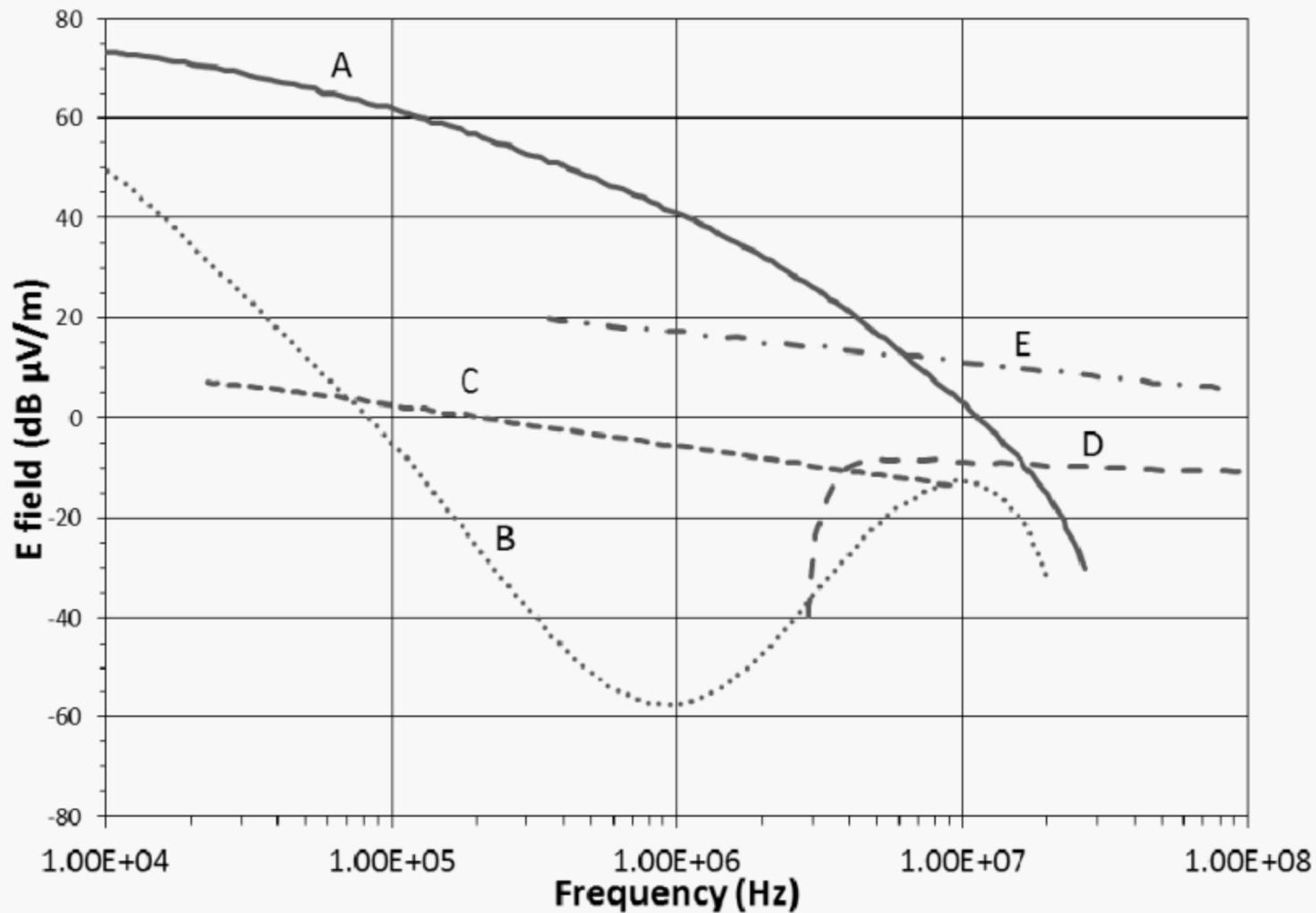
where

- B = 10 log (b)
- b is the bandwidth (in hertz)



- A: micropulsations not converted nor drawn
- B: minimum value expected of atmospheric noise
- C: maximum value expected of atmospheric noise

Figure 4—E field versus frequency [0.1 (10^{-1}) Hz to 10 000 (10^4) Hz] for 10 kHz bandwidth



- A: atmospheric noise, value exceeded 0.5% of time
- B: atmospheric noise, value exceeded 99.9% of time
- C: man-made noise, quiet receiving site
- D: galactic noise
- E: median city area man-made noise

Figure 5—E field versus frequency (10^4 Hz to 10^8 Hz) for 10 kHz bandwidth

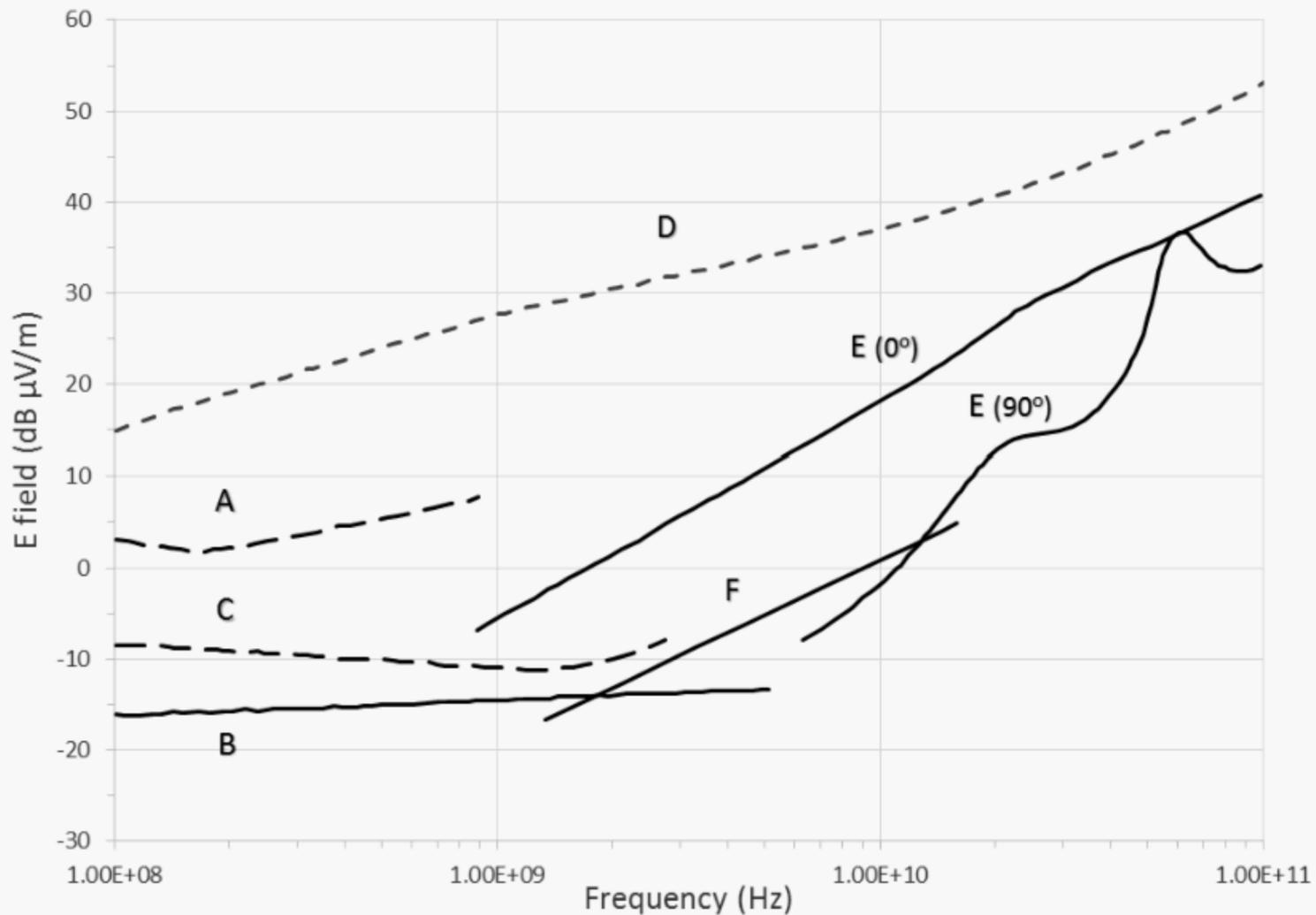
6.2.4 Radiated emissions

6.2.4.1 General

In the absence of any other standards, the requirements of 6.2.4 will assure that a reasonable level of radio protection is provided operating in the vicinity of the equipment to which these standards are applied.

It is understood that a radiation level expressed (as shown in Figure 7) in mV/m implies electric and magnetic field levels related by the free space impedance of 377Ω . It is true that the free space impedance may not hold in the near field, i.e., at frequencies where the measuring distance is less than $\lambda/2\pi$, where λ is the wavelength in meters. It is acceptable to make measurements at frequencies above 1600 kHz at a measuring distance of 30 m; frequencies above 4800 kHz at a measuring distance of 10 m and above 16 MHz at a measuring distance of 3 m. Extrapolation of the electric field limit values at a particular frequency to a different measuring distance requires 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, the measurement would be made either by 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 whether the source is electric or magnetic, 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, modification of the guidelines requires knowledge of the type of source producing the emissions and might require experimental validation, especially to account for ground plane effects.



- A: estimated median city area man-made noise
- B: galactic noise
- C: galactic noise (toward galactic center with infinitely narrow beamwidth)
- D: quiet sun ($1/2^\circ$ beamwidth directed at sun)
- E: sky noise due to oxygen and water vapor (very narrow beam antenna);
 upper curve 0° elevation angle, lower curve 90° elevation angle
- F: black body (cosmic background), 2.7 K

Figure 6—E field versus frequency (10^8 Hz to 10^{11} Hz) for 10 kHz bandwidth

The general radiated emissions guideline is shown in Figure 7. The levels specified here and on later figures and tables are for narrowband (modulated sine wave) emissions. For broadband emissions, a nominal 10 kHz bandwidth is assumed in the frequency range up to 30 MHz and 100 kHz for 30 MHz and above. However, adjustments in level or the bandwidth might be appropriate, depending on the 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 5. 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 7, it should be noted that for many types of equipment, e.g., 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 1 through Table 5).

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 limit distance to avoid extrapolation.

6.2.4.2 Radiated emissions—Class B limit

To protect radio reception in a Class B environment, the requirements of Figure 7 apply directly at a measurement distance of 10 m.

6.2.4.3 Radiated emissions—Class A limit

A Class A environment generally has 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 the immediate area.

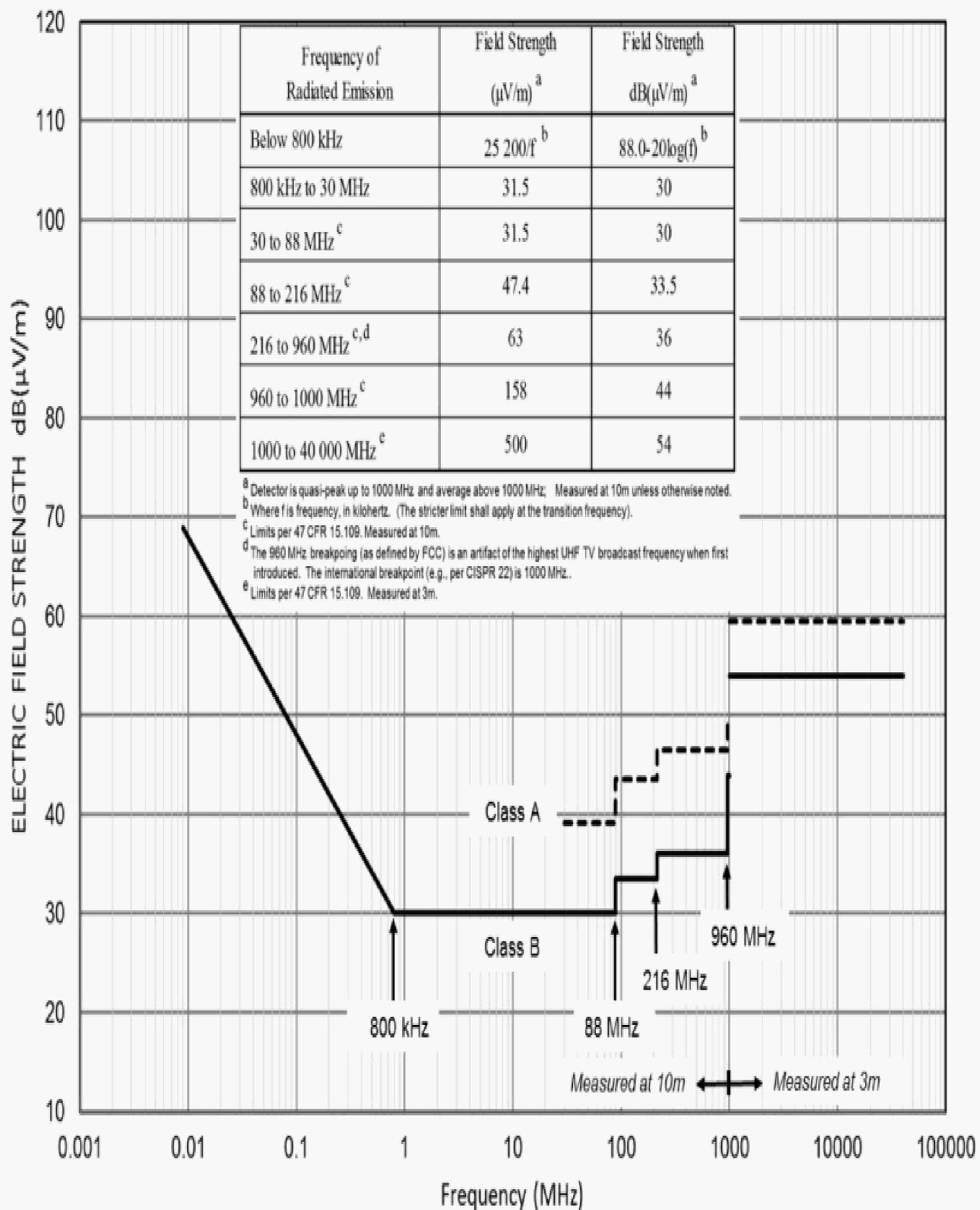
6.2.5 Conducted emissions

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

On the other hand, signal cables are usually connected between equipment with known specifications and which would be expected to have acceptable immunity. Of more concern is the possibility of common-mode currents on signal cables that can radiate and thus disturb equipment to which the cables are not directly connected. Limits on such emissions can be directly related to the radiated limits discussed in 6.2.4.2 and 6.2.4.3.

There can be relationships between common-mode and differential-mode phenomena but, from a practical point of view, it has not been the usual practice to place differential-mode emission limits on signal cables. The disturbance voltage (or current) limit is specified for a telecom port with the total common mode (TCM) load impedance of 150 Ω as seen by the EUT at the AE port during the measurement. This standardization is necessary in order to obtain reproducible measurement results, independent of the TCM impedance at the AE and the EUT. Limits are specified in CISPR 22:2008 and CISPR 32:2012. The limits in CISPR 32:2012 carry over the limits from CISPR 22:2008.

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 line-to-ground voltage limit and the common-mode current limit.



CLASS A represents products not sold to the general public (outside North America this may be referred to such names as "commercial", "light industrial" and "industrial").
CLASS B represents products sold to the general public (outside North America this is usually referred to as a "residential" environment)

Figure 7—Typical radiated emission limits

The use of a line-impedance stabilization network (LISN) to measure the disturbance voltage on ac power leads (also known as ac mains) is recommended in ANSI C63.4, CISPR 11:2010, CISPR 22:2008, and CISPR 32:2012. The Class B ac power line conducted emission voltage limits are shown in Table 1.

Table 1—AC power-line conducted emission voltage limits—Class B

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

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

For equipment intended to be operated in a Class A environment, the limits are as shown in Table 2. Those limits are recommended to provide protection for equipment located 30 m or more from the emitting equipment. Different limits might be more appropriate for other applications. For example, limits for conducted emissions above 4 kHz from terminal equipment intended for connection to the public telecommunications network can be found in 47 CFR 68.

Table 2—AC power-line conducted emission voltage limits—Class A

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

A recommended common-mode current emission limit is shown in Figure 8. It is derived from the radiated emission limits specified in Figure 7. The model used to convert from radiated emission to conducted emission was a 1 m vertical monopole, representing a vertical section of cable connecting to an equipment unit [B18]. This model is most representative of common-mode vertically polarized emission sources, which are the most common. Similar levels would be measured for horizontally polarized sources above a ground plane. This is based on a 10 m protection distance (see Table 3).

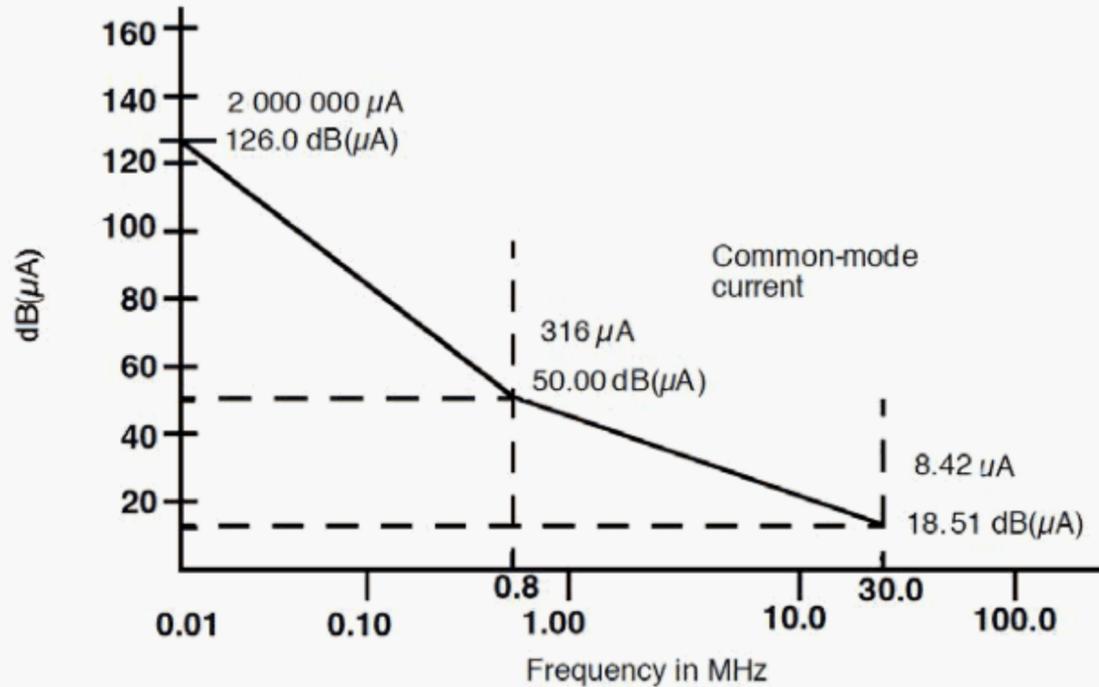


Figure 8—Common-mode conducted emission current limits

Table 3—Common-mode conducted emission current limits

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

One method of performing this test uses a current probe to measure the common-mode currents in shielded and unshielded cables. Note that in ANSI C63.4, this statement is made: “Basic specifications for current probes have been omitted, [sic] because LISN and voltage probe measurements remain preferred.”

In CISPR 16-1-2, 2004, subclause 5.1, the use and applicable frequency of current probes are specified. For example, the frequency range for which such probes are used is specified in Table 5.1.2. Annex B has typical construction techniques for current probes. It states the following:

“Frequency Range – Transfer impedance is calibrated over a specified frequency range; the range of individual probes is typically 100 kHz to 100 MHz, 100 MHz to 300 MHz, or 200 MHz to 1000 MHz.”

That leaves the range of 10 kHz to 100 kHz not covered by typical current probes unless specifically designed and calibrated to go down to 10 kHz.

6.2.6 Generic emission limit requirements

Generic emission requirements have been developed to provide specific requirements for applications where no other regulation or specific product standard applies. The requirements are specified in Table 4 and Table 5 for Class B and Class A installations, respectively, taking into consideration the distinction in the two classes of environments discussed in 6.2.1. (See CISPR 11:2010, CISPR 13:2009, and CISPR 22:2008 for specific product requirements.) Note that these limits are somewhat different from those discussed in 6.2.4 and 6.2.5.

A manufacturer needs to determine in which RF environment (Table 4 and Table 5) 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 4 are applied not only for the Class B environment, but also the Class A environments, or wherever the product is powered from the public mains supply. Correspondingly, the limits in Table 5 apply only for (heavy) industry where the product is powered from a non-public (industrial) supply.

Table 4—Generic emission requirements—Class B

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

Table 5—Generic emission requirements—Class A

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

6.2.7 Radiated and conducted emissions, special conditions

Under certain circumstances, different ambient levels might exist and different protection distances or levels might be appropriate. In such cases, for example, the relaxation of the limits for industrial areas might not be appropriate, and the Class B limit might be considered as an alternate. Still other limits might be appropriate for equipment that might be used on aircraft with sensitive navigation equipment that operates in the fuselage in an ambient noise environment well below that shown in Figure 2.

6.2.8 Emission allocation for components of a large system

6.2.8.1 General

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 subsystems in relation to the whole system, and anticipating whether the emissions are additive or not. 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 is to be 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 the legal entities that have jurisdiction, building wall attenuation can be included in calculating the subsystem allocations.

There are two empirically based methods that can be used in allocating emissions 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. The methods are useful for initial allocation of emissions. A conservative estimate based on either of the two 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 account for the inevitable inaccuracies involved in predicting how emissions will add (due to cabling, resonances, etc.).

6.2.8.2 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 Equation (2), where M is always a positive number, and represents the amount (in decibels) by which the subsystem must be lower in emissions level than the desired emissions level for the entire system.

$$M(\text{dB}) = (10 \log_{10} NS) + E + S + LE + LM \quad (2)$$

where

- NS is the maximum number of synchronously operated subsystems in one row (lineup) that contains the subsystem under test
- E is a 6 dB measurement error allowance
- S is 0 dB 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* is 0 dB or -3 dB if, respectively, the subsystem appears or does not appear in a peripheral position¹⁷
- LM* is 3 dB or 0 dB if, respectively, the subsystem appears or does not appear in more than one position¹⁸

The margin required for a nonsynchronous subsystem is given by Equation (3):

$$M(\text{dB}) = (5 \log_{10} NN) + E + S + LE + LM \quad (3)$$

where

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

6.2.8.3 Allocation method 2

For synchronously operated subsystems, the margin required for a subsystem is obtained from Equation (4):

$$M(\text{dB}) = 10 \log_{10} PDR \quad (4)$$

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 Equation (5):

$$M(\text{dB}) = 5 \log_{10} PDR \quad (5)$$

with *PDR* as specified for the synchronous case.

6.3 Immunity

6.3.1 General

Electronic devices must frequently operate in the presence of external RF fields. These fields may be due to one or more of the following:

- 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) Non-communication RF radiators such as industrial heating, medical diathermy machines, and digital computers

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

¹⁷ 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.

¹⁸ Subsystems appearing at multiple positions in the system, whether "interior" or at the periphery, generally do not have emissions that add linearly.

In addition to the continuous type of interference mentioned in item a), item b), and item c) of this subclause, other sources of interference produce transients and include electrostatic discharge (ESD), electrical fast transient bursts due to switched (on or off) equipment, and surges on power and other lines due to switching transients and lightning. IEC 61000-4-10:2001, IEC 61000-4-12:2006, IEC 61000-4-13:2002+AMD1:2009 and IEC 61000-4-16:2011 are the generally accepted test methods for power line disturbances. IEEE Std C62.41-1991 provides information on power line surge protection.

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 RF fields. This parallels the case of RF emission control as discussed in 6.2.1. 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.

6.3.2 General Performance Categories

General performance categories help in judging the response of the product when exposed to a particular test level. These performance categories are also known as follows:

- Acceptance criteria
- Failure criteria
- Performance degradation criteria

It is more general for the purposes of this recommended practice to lump these three descriptions into one, i.e., performance categories, described below.

Four general performance categories are specified for equipment immunity. They are based on the manufacturer's performance specifications. The performance criteria generally are as follows:

- a) Operation 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. 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) Operation 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. 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 equipment (components), corruption of software, or loss of data. Equipment must not become dangerous to the operator or the environment at any time.

6.3.3 RF immunity test levels

6.3.3.1 General

ANSI C63.15 is a recommended practice for immunity measurements and as such gives useful information that couples with the test levels provided in this section. As indicated in ANSI C63.15, the conducted

immunity (CI) and radiated immunity (RI) test methods do not universally apply to every product. Applicable test methods should be selected by a qualified EMC test engineer in consultation with the customer asking for immunity tests to be performed. The engineer then documents the test planning and the rationale for using particular immunity tests. The documentation is intended to

- a) Identify preferred or optional immunity test methods
- b) Describe specific measurement techniques and test levels
- c) Suggest product performance degradation criteria as applicable to general and specific products
- d) Identify test instrumentation specifications

In some circumstances, immunity levels other than those indicated in the following paragraphs might apply and should take precedence. Examples of such circumstances are regulations, manufacturer's specification, and user complaints. Equipment developed for military applications should use MIL-STD-461 for test procedures and test levels. The U.S. Department of Defense procurement activity will specify which version of MIL-STD-461 is applicable for a specific product.

6.3.3.2 Radiated immunity test levels

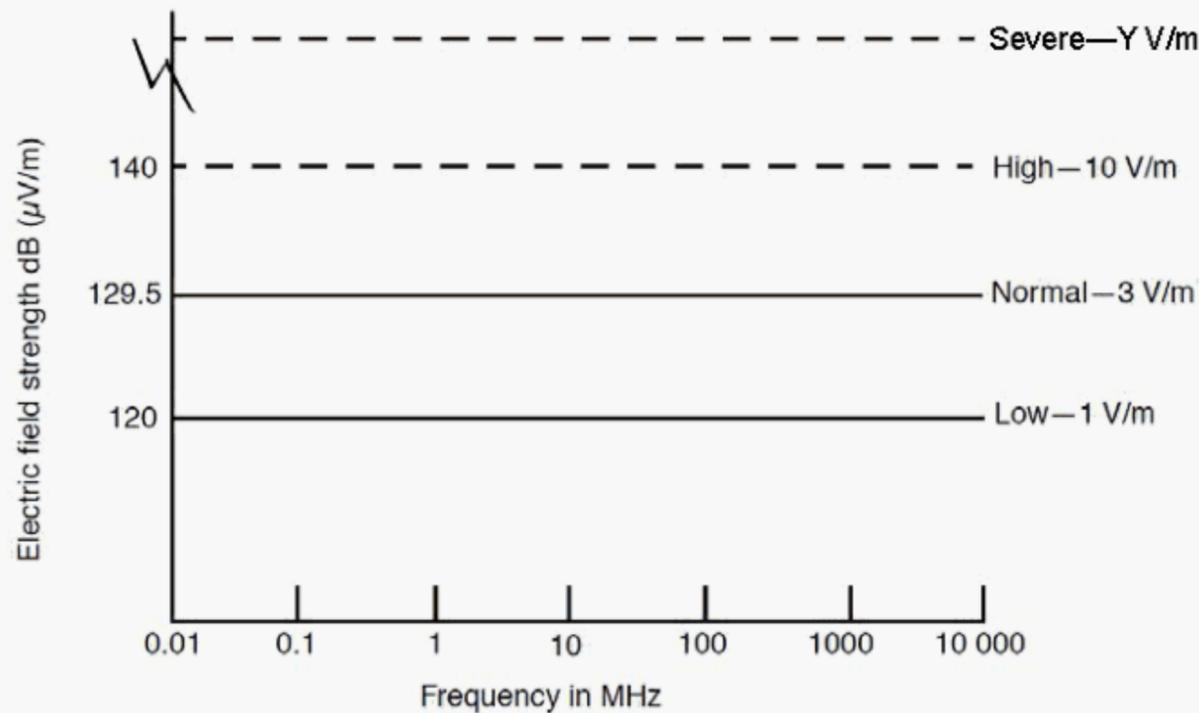
Definitive studies of the percentage of electronic devices in homes or businesses that encounter high radio frequency fields are limited to non-existent. However, it is known that radio frequency fields at some locations can be very high, for example, 32 V/m (150 dB μ V/m) 60 m away from a 50 kW non-directional AM broadcast transmitter antenna, 20 m directly in front of an 8 dB gain amateur-radio 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 all the locations where electronic equipment is used. It is estimated that less than 5% of these locations experience fields greater than 1 V/m. [B11], [B13], [B16].

As a consequence of the RF environment noted above, it is recommended that the minimum immunity for electronic equipment be 3 V/m (± 3 dB) (130 dB μ V/m ± 3 dB) for the electric field and an equivalent free-space conversion for the magnetic field ($H = E/377 \mu$ A/m, for E in μ V/m). Immunity testing replicates such fields usually at the front face of the EUT (or the closest extent of the EUT), calibrated in the absence of the EUT, for the frequency range shown in Figure 9.

It is suggested that the 3 V/m test level be applied to as much of the spectrum as possible to account for a continuous mode of immunity response. These responses are enhanced due to EUT resonances caused by variations in lead lengths, lead terminations, and cabinet or device dimensions which heightens the EUT response. It is further suggested that at least the applied field covers the range of 2 MHz to 1000 MHz.

It has to be noted that some devices will encounter higher fields and must be specially modified including the application of shielding and filtering to mitigate performance degradation of its operation. Where equipment is only tested to pass a lower field strength level such as 1 V/m, the equipment might not operate satisfactorily in certain environments known to have higher RF levels. Those devices whose reliable operation at all locations is essential for any reason should thus be designed for higher immunity levels as required for their application. These devices normally represent a very small proportion of the total number of devices, and a decision to meet the higher immunity levels should be made on an individual basis.

Figure 9 shows the range of test levels that are commonly invoked. The 3 V/m level is shown as the level normally indicated in test specifications. The two dash lines labeled: "High—10 V/m" and "Severe—Y V/m," are suggested to protect devices in the more severe RF environments noted in this subclause.



NOTE 1—The “Y” Severe level may be different from the “X” level in IEC 61000-4-3:2010, and may be at any negotiated level.

NOTE 2—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.

Figure 9—Radiated electric field immunity guidelines.

6.3.3.3 Conducted immunity test levels

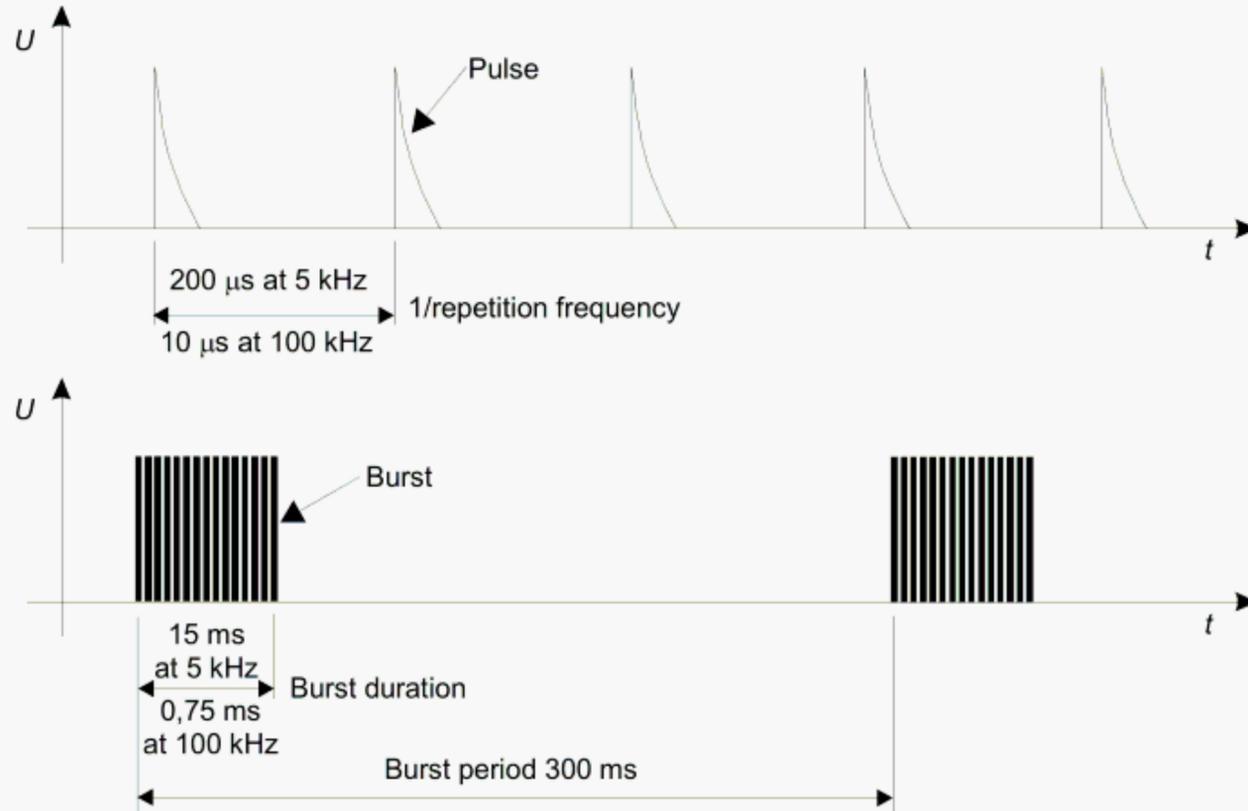
Conducted RF immunity test levels are specified for commercial applications using IEC 61000-4-6:2008 covering 150 kHz to 230 MHz, typically run only up to 80 MHz. The test levels correspond to equipment environments and are specified by manufacturers or their customers. The standard applies voltages with test amplitudes derived from 300 Ω loop impedances without the use of closed-loop monitoring of the applied voltage. Conducted current injection testing is allowed as an alternative test method in IEC 61000-4-6:2008 and does use current monitoring.

Conducted RF immunity test levels are specified for military applications using MIL-STD-461, covering 9 kHz to 400 MHz, with test levels corresponding to the equipment environment and criticality of the application. The DOD specifying authority imposes the appropriate test levels in the procurement process. The latest revisions of the standard specify injection of currents with test amplitudes derived from 100 Ω loop impedances and closed-loop monitoring of the injected current.

Direct correlation between these two techniques is not possible, as the commercial method is based upon an applied voltage while the MIL-STD method is based upon injected current. The two documents also use very different loop impedances for the generation of the drive levels during testing.

6.3.3.4 Fast transient and surge immunity test levels

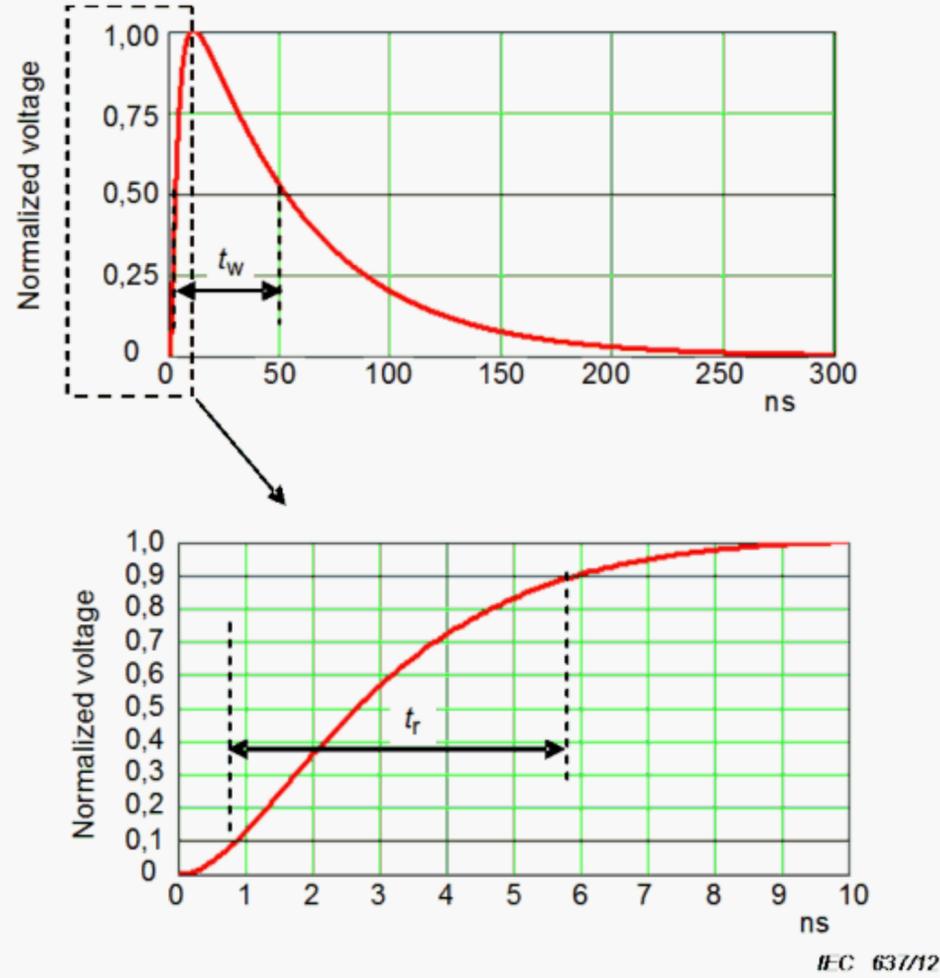
It is desirable to test equipment to determine its ability to withstand high-frequency, short-duration disturbance (chattering relay) bursts. The signals shown in Figure 10, chosen to be representative of powerline transients due to local switching and other inductive events, should be applied to all 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 11 except that the rise and duration times are 1.2 µs 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 61000-4-4:2012.



IEC 636/12

Reprinted with permission from IEC 61000-4-4:2012 (Figure 2).

Figure 10—Representation of an electrical fast transient/burst



IEC 637/12

Reprinted with permission from IEC 61000-4-4:2012 (Figure 3).

Figure 11—Ideal waveform of a single pulse into a 50 Ω load with nominal parameters $t_r = 5$ ns and $t_w = 50$ ns

6.3.3.5 Electrostatic discharge immunity test levels

The 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 61000-4-2:2008. 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 provides some protection, the requirement may be reduced. ANSI C63.15 and ANSI C63.16 provide additional information relative to ESD testing.

6.3.4 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 6. 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 specified for three categories of environments—Class B, Class A, and severe. Covered are: ESD, voltage dips and fluctuations, fast transients (bursts), and radiated and conducted RF phenomena.

6.3.5 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 occur near radio transmitting antennas, either on land or on ships. Also, high-level transients can appear in power conductors in large switching stations.

The levels given in the fifth column of Table 6 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 6—Generic immunity test levels

	Frequency of time char.	Test levels Class B	Test levels Class A	Test levels severe environment	Acceptance criteria ^a	Test method
Radiated H-field ^b	Pulse	—	—	100 A/m	a)	IEC 61000-4-9
Radiated H-field ^b	57 Hz to 63 Hz	3 A/m ^c	30 A/m	—	a)	IEC 61000-4-8
Radiated E-field	80 MHz to 6 GHz 80% mod. 1 kHz	3 V/m ^e	3 V/m ^e	30 V/m ² – 100 V/m ^e (commercial)	a)	IEC 61000-4-3 ^g RS103 ^f
	2 MHz to 40 GHz ^s 1 kHz PM 50% DC	—	—	200 V/m ^e (government/military)		
ESD	Electrostatic discharge	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	30% reduction	30% reduction	30% reduction	b) for 1/2 period	IEC 61000-4-11
	6 periods	60% reduction	60% reduction	60% reduction	c) for 6 periods	
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	±2 kV ^l	±6 kV	b)	IEC 61000-4-5 IEEE C62.45 ⁿ
Surge differential mode ^j	1.2/50 (8/20) μs	±1 kV ^l	±1 kV ^l	±4 kV	b)	IEEE C62.45 ⁿ IEC 61000-4-5
Fast transients power-port	5/50 ns 5 kHz rep rate	±1 kV	±1 kV	±4 kV	b)	IEC 61000-4-4
Fast transients signal port	5/50 ns 5 kHz rep rate	±0.5 kV ^o	±0.5 kV ^o	±2 kV ^o	b)	IEC 61000-4-4
RF common mode, 1 kHz, 80% AM ^j	150 kHz to 230 MHz ^d 10 kHz to 200 MHz.	3 V (rms) ^{e,t}	3 V (rms) ^{e,t}	10 V (rms) ^e Up to 109 dBuA (government/military)	a)	IEC 61000-4-6 CS114 ^f
Recreated GSM	824 MHz to 849 MHz 1850 MHz to 1915 MHz		30 V/m		a)	ANSI C63.9-2008 ^r

^a See 6.2.1.

^b Applicable only to equipment with magnetically sensitive components or circuitry.

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

^d X optional between 80 MHz and 230 MHz. See IEC 61000-4-6:2008.

^e Before modulation is applied.

^f See MIL-STD-461F.

^g Covers only frequencies between 80 MHz 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.

Table 6—Generic immunity test levels (continued)

^k Applicable to equipment 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 recommended to IEEE Std C62.45-2002 for protective devices and IEC 61000-4-5:2005 for finished equipment.

^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 is 3 V.

^r Also must comply with IEC 61000-4-3:2010 at 10 V/m.

^s Optional between 2 MHz to 30 MHz and 18 GHz to 40 GHz.

^t Product standards may impose a cable length restriction.

Annex A

(informative)

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Biographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

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