

American National Standard Recommended Practice for the Immunity Measurement of Electrical and Electronic Equipment

C63[®]

Accredited Standards Committee C63[®]—Electromagnetic Compatibility

Accredited by the
American National Standards Institute

IEEE
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American National Standard Recommended Practice for the Immunity Measurement of Electrical and Electronic Equipment

Accredited Standards Committee C63®—Electromagnetic Compatibility
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American National Standards Institute

Secretariat
Institute of Electrical and Electronics Engineers, Inc.

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C63®

Abstract: This immunity testing and test instrumentation specifications recommended practice complements the procedures for making emission measurements as specified in ANSI C63.4 and in ANSI C63.10. These immunity test methods can be of use to manufacturers who want to maximize product reliability and reduce customer complaints by improving the immunity of their products, beyond that required by applicable regulations, or by correcting problems experienced in deployment that are not related to regulatory requirements. This recommended practice generally covers the frequency range 30 Hz to 10 GHz.

Keywords: ANSI C63.15, electromagnetic compatibility, EMC, immunity testing, RF immunity

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Introduction

This introduction is not part of ANSI C63.15-2017, American National Standard—Recommended Practice for the Immunity Measurement of Electrical and Electronic Equipment.

Background of ASC C63® activity in preparing immunity standards

TV immunity in the early 1980s

In the early 1980s, television (TV) sets received their signals only over the air because cable and satellite reception were not available. The tuners had only limited shielding, if any. Radio-frequency signals from a variety of sources outside the TV bands interfered with TV reception. In 1982, legislation was passed by the U.S. Congress and President Reagan (Public Law 97-259) giving the Federal Communications Commission (FCC) the authority to require that home electronics equipment would have to meet radio-frequency interference susceptibility standards. This stemmed from the work at the time of Senator Barry Goldwater and House Representative Charles Vanik. Senator Goldwater was himself an amateur radio operator and certainly aware of the need for immunity of home electronics, especially to licensed broadcasters using frequencies outside of the TV bands.

At the time, ASC C63® was asked by the FCC to work with the Electronics Industry Association (EIA) to see if there were ways for manufacturers to add immunity to TVs so as not to require FCC regulations. A task force in ASC C63® Subcommittee 1 was set up to address this matter. After extensive discussions, the TV industry came up with designs that significantly increased the immunity of TVs to out-of-band signals. This was one of the first times that the voluntary standards community helped to solve a problem, thus precluding the need for regulations.

ASC C63® commences immunity standards work

The above background served to set the stage for the interest in ASC C63® to consider preparing immunity standard test methods. As such, the project was approved in Subcommittee 1 in the 1980s, for an addition to ANSI C63.4 for measurement methods, and an addition to ANSI C63.2 for measurement instrumentation. These would eventually be removed as additions of ANSI C63.4 and ANSI C63.2 and made into ANSI C63.15 solely covering immunity. Don Heirman was named as the chairman of the WG on Immunity with the assistance of Ray Magnuson. A ballot was then taken of the work in 1983. The ballot had many comments but, more importantly, eight negative votes. Work then proceeded to resolve the comments. Bill Hayes took over the measurement instrumentation portion of the task at that time. In parallel there was also major activity in immunity test methods starting by the International Electrotechnical Commission (IEC). This required decisions on how to proceed with the work of ASC C63®. The outcome was that the ASC C63® work on immunity was stalled for several years. However, the WG did contribute in this timeframe to the military work on commercial off-the-shelf procurements, as well as immunity text for ANSI C63.12 in the mid-1990s. Further revisions were made to the ASC C63® draft during this time, headed by Steve Bloom, but at a slow rate because the work in the IEC was gaining speed.

Draft standard renamed to ANSI C63.15 draft

The Subcommittee 1 projects were called project 1-1.1 (Immunity measurement methods) and project 1-1.3 (Immunity instrumentation) for development of the overall standard. The projects were combined into one document and given the number C63.15 as early as 1999. In early 2000, another draft was ready for ballot; the C63.15 number was continued. The ballot was taken and the document still failed to get sufficient approval votes. At that time, Herb Mertel assumed the WG chairmanship, working to prepare another draft, taking into account the comments that would require extensive changes to the draft standard. By 2003, it

was identified as a recommended practice. In 2004, Mike Windler took over the task of editing the document. The ballot again failed in 2005 with substantial negative comments. At that time the project was shifted to Subcommittee 5 because that subcommittee deals with immunity standards with its genesis to handle the TV interference issue as noted above. In 2006, a ballot was taken and that time it passed in the parent committee. The final editing was completed in Fall 2008, with ANSI and IEEE processing completed for publication in 2010.

After publication in 2010, a working group was assembled to update the material and to include more on automotive immunity testing as well as an additional quasi-static test among other new material. The results of this work are contained in this edition of the document. The major additions and modifications are listed as follows:

- a) Automotive immunity testing; conducted testing is in 5.10 and 5.11, radiated testing is in 6.9 and 6.10
- b) Immunity to nearby RF wireless communications equipment (proximity fields), in 6.7
- c) Quasi-static immunity testing; the test method is in 6.8
- d) More complete specification of the contents of the evaluation (test) report (Clause 7)
- e) An annex (i.e., Annex C) identifying applicable information sources by standard, clause, figure, and table

Acknowledgments

The Working Group thanks the International Electrotechnical Commission (IEC) for permission to reproduce Information from its International Standards IEC 60601-1-2:2007, IEC 60601-4-2:2016, IEC 61000-4-4:2012, IEC 61000-4-5:2014, and IEC 61000-6-1:2005. All such extracts are copyright of IEC, Geneva, Switzerland. All rights reserved. Further information on the IEC is available from www.iec.ch. IEC has no responsibility for the placement and context in which the extracts and contents are reproduced by the author, nor is IEC in any way responsible for the other content or accuracy therein.

Grateful acknowledgment is made to the International Standardization Organization for permission to reprint and modify material from ISO 7637-2:2004, ISO 7637-2:2011, and ISO 16750-2:2012.

Grateful acknowledgment is made to the Society for Automotive Engineers for permission to reprint and modify material from SAE J1113-22:2003 and SAE J1113-26:2014.

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American National Standard Recommended Practice for the Immunity Measurement of Electrical and Electronic Equipment

1. Overview

This recommended practice is intended to:

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

Wherever possible, existing voluntary standards are used and summarized. It should be noted that the techniques listed herein should in no way limit the user to a particular method to increase product immunity. The immunity levels in this document are recommendations. Should product classifications and types have other immunity levels that apply, those shall take precedence. Equipment developed for military applications should use MIL-STD-461G-2015¹ or later editions for test procedures and test levels.

The conducted immunity and radiated immunity test methods in this recommended practice do not universally apply to every product. Applicable test methods should be selected. A qualified electromagnetic compatibility (EMC) engineer should document test planning and the rationale for using particular immunity tests.

In addition, this document complements the procedures for making emission measurements as specified in ANSI C63.4 (for unintentional radiator products and functions) and in ANSI C63.10 (for intentional radiator products and functions). These immunity test methods are intended to be used by manufacturers who want to maximize product reliability and reduce customer complaints by improving the immunity of their products. This additional immunity is generally beyond that required by applicable regulations, and often is based on correcting problems experienced in deployment that are not related to regulatory requirements. This recommended practice generally covers the frequency range 30 Hz to 10 GHz.

The annexes provide additional information that could be useful in performing immunity tests. Annex A provides a tutorial on immunity testing and lists performance criteria (pass criteria or fail criteria) from several standards. Annex B lists recommended test equipment. Annex C identifies the equivalencies between the provisions, figures, and tables in this document relative to the original source documents.

¹ Information on references can be found in Clause 2.

As a general consideration, the expressions “test” or “testing” and “measurement” are sometimes used indiscriminately. However, testing often refers to immunity (usually a go/no-go test) and measurement is likely to refer to emission (normally the emission level is measured and recorded as a function of frequency). For consistency, this recommended practice uses the terms “test procedure” and “test method.”

Throughout this document, there is information from source standards that is repeated as basic information for immunity testing. While this document is a guide with recommendations and no requirements, there are normative requirements when references with such requirements are reproduced. These statements are generally identified by the use of the normative verb “shall.” In addition, for the purposes of this recommended practice, the following use of verbs signifies how they are used in this document:

- “Should” means that compliance with a test is recommended but is not mandatory for following this recommended practice.
- “May” is used to describe a permissible way to follow this recommended practice.

NOTE—The preceding verb use statements are adapted from 10.2.2 of the *2014 IEEE-SA Standards Style Manual* (<https://development.standards.ieee.org/myproject/Public/mytools/draft/styleman.pdf>).²

2. References

The following references are intended to assist the user, and are listed because they have direct application for the test methods summarized in this recommended practice. 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. Throughout this document, in-text reference to a specific clause, subclause, table, or figure of another document is dated even if the undated version of the document is listed in this clause.

ANSI C63.2, American National Standard for Specifications of Electromagnetic Interference and Field Strength Measuring Instrumentation in the Frequency Range 9 kHz to 40 GHz.³

NOTE—Throughout this document, citations to ANSI C63.2 also serve as indirect citations to CISPR 16-1-1, because ANSI C63.2 constitutes a U.S. National Standard adoption of CISPR 16-1-1 for radio disturbance measurement instrumentation while also retaining the unique requirements that are not in CISPR 16-1-1 but that are still used by certain domestic organizations.

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

ANSI C63.10, American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices.

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

ANSI C63.18-2014, American National Standard Recommended Practice for an On-Site, Ad Hoc Test Method for Estimating Electromagnetic Immunity of Medical Devices to Radiated Radio-Frequency (RF) Emissions from RF Transmitters.

ANSI C63.27, American National Standard for Evaluation of Wireless Coexistence.

² Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

³ ASC C63[®] publications are available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>) or from the American National Standards Institute (<http://www.ansi.org/>).

ANSI/TIA-470.110-D-2014, Telecommunications – Telephone Terminal Equipment – Transmission Requirements for Analog Telephones with Handsets.

ANSI/TIA-631-B-2011, Telecommunications – Telephone Terminal Equipment – Radio Frequency Immunity Requirements.

ANSI/TIA-920.110-B-2015, Telecommunications – Communications Products – Transmission Requirements for Digital Interface Communications Devices with Handsets.

Bronaugh, E. L., “Helmholtz coils for EMI immunity testing: stretching the uniform field area,” *IEEE Seventh International Conference on Electromagnetic Compatibility*, York, UK, pp. 169–172, 1990.

CISPR 16-1-1:2010-11, Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods—Part 1-1: Radio Disturbance and Immunity Measuring Apparatus—Measuring Apparatus, Ed. 3.1.⁴

CTA-544-C R-2014, Low Frequency Immunity of Tuners in a Cable System.⁵

CTA CEA/IS-31, Recommended Design Guideline, Rejection of Educational Interference to Channel 6 Television Reception.

CTA CEA/IS-16-A, Immunity of Television Receivers and Video Cassette Recorders (VCRs) to Direct Radiation From Radio Transmissions, 0.5 to 30 MHz.

DI-EMCS-80200C, Electromagnetic Interference Test Report (EMITR), Data Item Description, Nov. 30, 2007.⁶

FCC KDB Publication 414788, “Immunity testing on open area test site,” Office of Engineering and Technology (OET) Laboratory Division Knowledge Database (KDB), Federal Communications Commission (FCC).⁷

FMC1278, Electromagnetic Compatibility Specification for Electrical/Electronic Components and Subsystems, July 1, 2015.⁸

IEC 60601-1-2:2007, Medical electrical equipment – Part 1-2: General requirements for basic safety and essential performance – Collateral Standard: Electromagnetic compatibility – Requirements and tests.⁹

IEC 60601-1-2:2014, Medical electrical equipment – Part 1-2: General requirements for basic safety and essential performance – Collateral Standard: Electromagnetic disturbances – Requirements and tests.

⁴ CISPR documents are available from the International Electrotechnical Commission (<http://www.iec.ch/>) and the American National Standards Institute (<http://www.ansi.org/>).

⁵ Concerning document source institutional designations for background, one antecedent organization of CEA can trace its roots to the Radio Manufacturers Association (RMA) in 1924. In 1950, it changed its name to Radio-Television Manufacturers Association (RTMA). In 1953, it changed its name to Radio-Electronics-Television Manufacturers Association (RETMA). It was then the Electronic Industries Association (EIA) from 1957 to 1998, when it became the Electronic Industries Alliance. In 1995, EIA's Consumer Electronics Group (CEG) became the Consumer Electronics Manufacturers Association (CEMA). In 1999, the trade group's name changed to the Consumer Electronics Association (CEA), and CEA became an independent sector of the Electronic Industries Alliance (EIA; known as Electronic Industries Association until 1997). EIA ceased operations in 2011, and the former sectors of EIA became the Electronic Components Association (ECA), Joint Electron Device Engineering Council (JEDEC), Government Electronics and Information Technology Association (GEIA; was part of TechAmerica, now part of CompTIA), Telecommunications Industry Association (TIA), and Consumer Electronics Association (CEA). CEA recently changed its name to Consumer Technology Association (CTA).

⁶ MIL publications are available from the U.S. Department of Defense (<http://quicksearch.dla.mil/>).

⁷ FCC KDB Publication 414788 is available from the Federal Communications Commission (www.fcc.gov/labhelp).

⁸ FMC1278 is available from the Ford Motor Company (www.fordemc.com/docs/download/FMC1278.pdf).

⁹ IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch>) and the American National Standards Institute (<http://www.ansi.org/>).

IEC TR 60601-4-2:2016, Medical electrical equipment – Part 4-2: Guidance and interpretation – Electromagnetic immunity: performance of medical electrical equipment and medical electrical systems.

IEC 61000-4-3:2006, Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test.¹⁰

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

IEC 61000-4-5:2014, Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test.

IEC 61000-4-6:2013, Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields.

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 61000-4-20:2010, Electromagnetic compatibility (EMC) – Part 4-20: Testing and measurement techniques – Emission and immunity testing in transverse electromagnetic (TEM) waveguides.

IEC 61000-4-21:2011, Electromagnetic compatibility (EMC) – Part 4-21: Testing and measurement techniques – Reverberation chamber test methods.

IEC 61000-4-39:2017, Electromagnetic Compatibility (EMC) – Part 4-39: Testing and measurement techniques – Radiated fields in close proximity – Immunity test.

IEC 61000-6-1:2005, Electromagnetic compatibility (EMC) – Part 6-1: Generic Standards – Immunity for residential, commercial and light-industrial environments.

IEC IEV, IEV Online, (<http://www.electropedia.org/>).

IEEE Std 145™-2013, IEEE Standard for Definitions of Terms for Antennas.^{11, 12}

IEEE Std 299™-2006, IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures.

IEEE Std 299.1™-2013, IEEE Standard Method for Measuring the Shielding Effectiveness of Enclosures and Boxes Having All Dimensions between 0.1 m and 2 m.

IEEE Std 1309™-2013, IEEE Standard for Calibration of Electromagnetic Field Sensors and Probes (Excluding Antennas) from 9 kHz to 40 GHz.

IEEE Std C95.1™-2005, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.

ISO 7637-1:2015, Road vehicles – Electrical disturbances from conduction and coupling – Part 1: Definitions and general considerations.

ISO 7637-2:2004, Road vehicles – Electrical disturbances from conduction and coupling – Part 2: Electrical transient conduction along supply lines only.¹³

¹⁰ IEC 61000-4-3:2006 includes two amendments, Amd1:2007 and Amd2:2010.

¹¹ IEEE publications are available from The Institute of Electrical and Electronics Engineers, Inc. (<http://standards.ieee.org/>).

¹² The IEEE standards or products referred to in Clause 2 are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.

ISO 7637-2:2011, Road vehicles – Electrical disturbances from conduction and coupling – Part 2: Electrical transient conduction along supply lines only.

ISO 11452-9:2012, Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 9: Portable transmitters.

ISO 16750-1:2006, Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 1: General.

ISO 16750-2:2012, Road vehicles – Environmental conditions and testing for electrical and electronic equipment – Part 2: Electrical loads.

ISO/IEC 17025:2005, General requirements for the competence of testing and calibration laboratories.¹⁴

MIL-HDBK-454B:2007, General Guidelines for Electronic Equipment.¹⁵

MIL-STD-461G-2015, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.

NTIS PB81244857, July 1981: Using a TEM Cell for EMC Measurements of Electronic Equipment, Crawford, M. L.; Workman, J. L. [Originally published as NBS TN 1013.]¹⁶

RTCA DO-160G Change 1, Environmental Conditions and Test Procedures for Airborne Equipment, 2014.¹⁷

RTCA DO-357, User Guide: Supplement to DO-160G, 2014.

SAE J1113-1:2013, Electromagnetic Compatibility Measurement Procedures and Limits for Components of Vehicles, Boats (up to 15 m), and Machines (Except Aircraft) (16.6 Hz to 18 GHz).¹⁸

SAE J1113-22:2003, Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Part 22: Immunity to Radiated Magnetic Fields.

SAE J1113-26:2014, Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Immunity to AC Power Line Electric Fields.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹⁹

The definitions in ANSI C63.14 apply. Definitions in particular product standards or in applicable regulations take precedence.

¹³ ISO publications are available from the International Organization for Standardization (<http://www.iso.org/>) and the American National Standards Institute (<http://www.ansi.org/>).

¹⁴ ISO/IEC 17025:2005 includes one corrigendum, Cor1:2006.

¹⁵ MIL publications are available from the U.S. Department of Defense (<http://quicksearch.dla.mil/>).

¹⁶ Available from the U.S. Department of Commerce, National Technical Information Service (NTIS), National Technical Reports Library (NTRL) (<https://ntrl.ntis.gov/>).

¹⁷ RTCA publications are available from the Radio Technical Commission for Aeronautics (<http://www.rtca.org/>).

¹⁸ SAE publications are available from the Society of Automotive Engineers (<http://www.sae.org/>).

¹⁹ *IEEE Standards Dictionary Online* subscription is available at: <http://dictionary.ieee.org..>

apparatus: Device or assembly of devices that can be used as an independent unit for specific functions. (IEV 151-11-22)

NOTE—The term “apparatus” sometimes implies use by skilled persons for professional purposes.

component: Constituent part of a device that cannot be physically divided into smaller parts without losing its particular function. (IEV 151-11-21)

coupling/decoupling network (CDN): Electrical circuit incorporating the functions of both the coupling and decoupling networks. (IEC 61000-4-6:2013-10)

NOTE 1—A coupling network is an electrical circuit for transferring energy from one circuit to another with a defined impedance.

NOTE 2—A decoupling network is an electrical circuit for minimizing effects of test signals applied to the equipment-under-test (EUT) on other devices, equipment, or systems that are not under test.

NOTE 3—Coupling and decoupling devices can be integrated into one box (coupling and decoupling network (CDN)) or they can be in separate networks.

dBrnC: Noise power in decibels above a reference noise measured by a set with C-message weighting.

dBSPL: Sound pressure level in decibels relative to a particular noise as a reference source.

device: Material element or assembly of such elements intended to perform a required function. (IEV 151-11-20)

NOTE—A device may form part of a larger device.

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

NOTE 1—An electromagnetic disturbance can be electromagnetic noise, an unwanted signal, or a change in the propagation medium itself.

NOTE 2—In English, the terms “electromagnetic disturbance” and “electromagnetic interference” designate, respectively, the cause and the effect, but they are often used indiscriminately.

electromagnetic emission: The phenomenon by which electromagnetic energy emanates from a source. (IEV 161-01-08)

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

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

equipment: Single apparatus or set of devices or apparatuses, or the set of main devices of an installation, or all devices necessary to perform a specific task. (IEV 151-11-25)

NOTE—Examples of equipment are a power transformer, the equipment of a substation, and measuring equipment.

immunity (to a disturbance): The ability of a device, equipment, or system to perform without degradation in the presence of an electromagnetic disturbance. (IEEE Standards Dictionary Online) (IEV 161-01-20).

NOTE—Immunity is the characteristic of not being susceptible; susceptibility can result from an electromagnetic disturbance.

installation: One apparatus or a set of devices or apparatuses associated in a given location to fulfil specified purposes, including all means for their satisfactory operation. (IEV 151-11-26 MOD)

near-field region: That part of space between the antenna and the far-field region. (IEEE Std 145-2013)

quasi-static fields: Fields that have the same spatial patterns as static fields but vary with time.

system: Set of interrelated elements considered in a defined context as a whole and separated from their environment. (IEV 151-11-27)

NOTE 1—A system is generally defined with the view of achieving a given objective, e.g., by performing a definite function.

NOTE 2—The system is considered to be separated from the environment and the other external systems by an imaginary surface, which cuts the links between them and the system.

NOTE 3—The term “system” should be qualified when it is not clear from the context to what it refers, e.g., control system, colorimetric system, system of units, transmission system.

3.2 Acronyms and abbreviations

ac	alternating current
AE	auxiliary equipment
AM	amplitude modulation, amplitude modulated
AWG	American wire gauge
BCI	bulk current injection
BER	bit error rate
CDMA	code division multiple access
CDN	coupling decoupling network
CEA	Consumer Electronics Association
CISPR	Comité International Spécial des Perturbations Radioélectriques
CTA	Consumer Technology Association (formerly Consumer Electronics Association)
CW	continuous wave
dc	direct current
DECT	Digital Enhanced (originally European) Cordless Telecommunications
EIA	Electronic Industries Alliance (until 1997 Electronic Industries Association)
EM	electromagnetic
EMC	electromagnetic compatibility
EMF	electromotive force [used with the unit V (emf)]
EMI	electromagnetic interference
EUT	equipment-under-test ²⁰
FCC	Federal Communications Commission
FM	frequency modulation, frequency modulated
FRS	Family Radio Service

²⁰ Some EMC publications equivalently use the abbreviation DUT (device-under-test) rather than EUT.

GMRS	General Mobile Radio Service
GSM	Global System for Mobile Communications (originally Groupe Spécial Mobile)
GTEM	Gigahertz transverse electromagnetic, GTEM cell
I/O	input/output
iDEN	Integrated Digital Enhanced Network
IEC	International Electrotechnical Commission
IEV	International Electrotechnical Vocabulary
IF	intermediate frequency
ISO	International Organization for Standardization
KDB	FCC Knowledge Database
LF	low frequency
LISN	line impedance stabilization network ²¹
LTE	Long-Term Evolution
NBS	National Bureau of Standards
NTIS	National Technical Information Service
PE	protective earth
PRF	pulse repetition frequency
RF	radio frequency
RFID	radio frequency identification
rms	root mean square
ROLR	receive objective loudness rating
RP	reference point
RTCA	Radio Technical Commission for Aeronautics
SAE	SAE International (originally established as the Society of Automotive Engineers)
T-LISN	telecommunication-port line impedance stabilization network ²²
TEM	transverse electromagnetic
TETRA	Terrestrial Trunked Radio (originally known as Trans-European Trunked Radio)
TIA	Telecommunications Industry Association
TTE	telephone terminal equipment ²³
TV	television
UMTS	Universal Mobile Telecommunications System
VCR	video cassette recorder
WLAN	wireless local area network

²¹ Some EMC publications equivalently use the abbreviation AMN (artificial mains network) or V-AMN (V-network AMN) rather than LISN.

²² A T-LISN or T-ISN measures asymmetrical disturbance voltage in symmetrical data transmission systems. Some EMC publications equivalently use the abbreviation AAN (asymmetric artificial network) rather than T-LISN.

²³ Some EMC publications use TTE as an abbreviation for telecommunications (telecommunication) terminal equipment.

4. General considerations

4.1 Safety precautions

WARNING

Electric Shock Hazard: Precautions against electric shock hazard should be taken when ac-operated test instrumentation is used and when test instrumentation is connected to power circuits. There are numerous requirements for leakage currents, and the precautions given in manufacturers' manuals and local codes need to be considered. The following are two examples:

In MIL-HDBK-454B, it is specified that in normal use if the open circuit potential to ground is more than 25 V (ac) and the current with a 1500 Ω load is more than 4 mA (dc) and 1 mA (ac), then a shock hazard exists.

In Europe, the shock hazard amplitude is 0.75 mA for handheld equipment and 3.5 mA for floor standing equipment.

WARNING

Nonionizing Radiation Exposure Hazard: IEEE Std C95.1 specifies safety levels and guidelines with respect to human exposure to radio frequency electromagnetic fields. Fields that exceed these safety levels are possible when using the test instrumentation in this recommended practice, particularly when the test instrumentation is used to perform radiated immunity testing. Precautions against exposing personnel to these electromagnetic fields should be taken.

4.2 Measurement tolerances

The general tolerances are derived from MIL-STD-461G-2015. Unless otherwise stated for a particular measurement, the parameter tolerances shall be as follows:

- a) Distance: $\pm 5\%$
- b) Frequency: $\pm 2\%$
- c) Time (waveforms): $\pm 5\%$
- d) Resistors: $\pm 5\%$
- e) Capacitors: $\pm 20\%$

4.3 Input power requirements

If the test instrument requires ac power, it should operate on a supply that meets its specifications for voltage and frequency. The test instrumentation should have adequate power-line filtering to preclude erroneous or undesirable operation due to power-line interference.

4.4 Step size and dwell time

4.4.1 Step size

For tests in which the immunity test signal is stepped through a range of frequencies, the step size should be no greater than 1% (i.e., next frequency = preceding frequency $\times$ 1.01; or using symbols, $f_{i+1} = f_i \times 1.01$, where f is frequency and i is an integer).

4.4.2 Dwell time

4.4.2.1 General

For tests in which the immunity test signal is stepped through a range of frequencies, the immunity test signal should dwell at each frequency step for a duration that is determined based on the following:

- a) The settling time of the immunity test system
- b) The time required for the equipment-under-test (EUT) to be exercised or controlled (if applicable) and respond to the immunity test signal
- c) The time required for the tester or monitoring system to observe potential EUT responses to the immunity test signal

The minimum dwell time should be in the range of 1 s to 3 s. The response time should consider the slowest responding function. For systems that have multiple individual parameters or subsystems, each of which would yield a different dwell time, the value used should be the maximum of the individually determined dwell times.

4.4.2.2 Equipment with long response times

Some equipment has very long response times. In this case, the dwell time might be able to be reduced using the following techniques, but it shall not be less than 1 s:

- a) If faster-responding signals can be used to determine the effect of the immunity test signal on the EUT, the dwell time can be reduced if the faster-responding signals are monitored.
- b) If special software can be used that shortens EUT cycle times, this could help reduce the dwell time.
- c) If higher immunity test levels result in faster response of the EUT, this could help reduce the dwell time.

Examples of (medical) equipment with long response times are as follows:

- A pulse oximeter might display a value averaged over several cardiac cycles.
- It might take several minutes to detect changes in the flow rate of an infusion pump.
- A ventilator might require several breath cycles to respond to a test signal.

5. Conducted immunity

5.1 General

Interference caused by conducted or radiated disturbances can degrade electrical and electronic product operation as it enters the product via ac power, dc power, signal, communication, telemetry lines, and receive antenna input. Radio-frequency (RF) radiated disturbances can also couple into such cables and produce interfering signals. Hence, the product cables shall be immune to common-mode current conducted interfering signals, which enter the product in a conducted-signal manner, flowing relative to the ground plane, and are comprised of steady-state, transient, and other signal types typically found in RF ambient and end-use locations.

5.2 Power-line immunity, 30 Hz to 150 kHz

5.2.1 General

This test method is used to verify the ability of the EUT to function as intended with ripple voltages present on power leads. Because the applied voltage is coupled in series using a low-impedance transformer, Kirchhoff's voltage law requires that the voltage appearing across the transformer output terminals drops around the circuit loop formed by the EUT input and the power source impedance. The voltage specified by the product specification is measured across the EUT input circuit elements because part of the transformer voltage can be expected to drop across the source impedance.

5.2.2 Test procedure

Use the test procedure given in Method CS101 of MIL-STD-461G-2015. Recommended test equipment is listed in B.1.

5.2.3 Performance criteria

Immunity performance criteria should be established before the test using the guidelines in Annex A and communicated to the tester or test lab prior to the test.

5.2.4 Suggested immunity levels

The suggested immunity level is shown in Figure CS101-1 of MIL-STD-461G-2015, Curve 1.

This immunity level is 136 dB μ V (6 V) from 30 Hz to 5 kHz on lines greater than 28 V nominal, and the immunity level decreases as a log function (linear on a log scale) to 106.5 dB μ V (0.21 V) at 150 kHz.

NOTE—Test voltages are in terms of the rms value of a sine wave.

5.3 Conducted RF immunity on power and I/O (signal) lines

5.3.1 General

This test method is used to verify the ability of the EUT to function as intended with modulated RF common-mode signals that might be present on power and I/O lines. There are two widely used standards for this type of conducted immunity testing; military (MIL-STD-461G-2015) and commercial (IEC 61000-4-6). The choice is contractual, as required by the customer or dictated by the installation environment. With the recent emphasis on commercial off-the-shelf (COTS) equipment, even for military applications, the acquisition requirement usually stipulates the type of testing needed.

Military testing injects currents into undefined (i.e., as installed) loop impedances. The test signal is inductively coupled using a current probe. Faraday's law predicts induced voltages in such a loop circuit from the resultant current flow, with the voltage drops dependent on the various impedances present. The test method requires checking for resonant, infinitesimally small impedances, then limiting the injected current in these cases. Interfering currents are induced into all wires at a connector interface simultaneously (in common mode), which simulates actual use. Auxiliary equipment (AE) shall be decoupled as required to preclude malfunctions.

Testing is required on intact complete power cables, and on power cables with the neutral or grounded conductors removed, to evaluate common-mode coupling to configurations that might be present in different end-use installations. In some end-use installations, the neutral or grounded wire is routed along with the line

conductor, while in other cases the neutrals or grounded conductors are tied to the grounded system structure near the utilization (load) equipment. The entire grounded system structure is used as the power return path.

Commercial testing couples voltages using coupling-decoupling networks (CDNs) on power and I/O wiring in common-mode. The use of the CDNs sets the loop impedance so that the test voltage levels are maintained (no over-testing when using CDNs). The decoupling section helps preclude malfunctions, due to the interfering voltages, of the AE used to monitor EUT acceptance. Interfering voltages are coupled onto all wires of an interface simultaneously, in common-mode, to simulate actual use. Inductive coupling or an electromagnetic (EM) clamp can also be used for commercial testing as an alternative to CDNs; this can be a preferable method if a CDN is not available, e.g., for a custom I/O cable.

Each coupling method requires a “level-setting” procedure to determine the required drive level for that coupling method, test level, and test setup. This “drive table” is then played back by the computer (with 80% amplitude modulation (AM) applied; 1 kHz or 400 Hz) during the test run, with an appropriate dwell time (usually 2 s) at each frequency, and the performance of the EUT is monitored by decoupled AE for failures.

5.3.2 Test procedure

5.3.2.1 General

For military testing, use the test procedure given in Method CS114 of MIL-STD-461G-2015 from 10 kHz to 200 MHz. The procedure requires both inducing a current and measuring such current, to preclude over-testing into zero (infinitesimally small) impedance loads from occurring. Note also that during playback, the limit on induced current is not the calibration curve, but instead is defined in 5.12.2 of MIL-STD-461G-2015. These limits can be tailored to the EUT based on actual usage environment.

For commercial testing, IEC 61000-4-6 can be used over the frequency range 150 kHz to 80 MHz (typically) or as high as 230 MHz. CDNs are now available for almost every type of I/O line, including Ethernet. The use of CDNs is required if they are appropriate for the line being tested. A level-setting procedure is required for each CDN. All power and I/O wiring should have input-terminated CDNs before level-setting or testing begins on any of them. In the case of some complex lines, such as with medical products, the product may not function due to CDN impedance or use of a CDN may not be appropriate, then use of the EM clamp is appropriate.

The IEC 61000-4-6 commercial standard uses a logical decision tree to guide in the choice of coupling method. First, it asks whether CDNs are suitable. If a terminated CDN is inserted into the power or I/O lines of the EUT, and those lines continue to function, then that CDN should be used on those lines. A CDN should be used whenever possible, and the odds of passing the test are enhanced by the decoupling section of the CDN. Extra mains (M3) CDNs or other CDNs for the AE can be needed with all coupling methods.

Recommended test equipment is listed in B.2.

5.3.2.2 Use of CDNs

In the level-setting diagram of Figure 1, note that the three conductors present in the CDN (for three-wire single-phase power in this case) are shorted together at the input and output of that CDN and terminated into 150 Ω to each side (series 100 Ω resistor and 50 Ω load or sensor).

The power meter readings needed for testing at the three levels in the standard are shown in Table 1.

A -15.6 dB correction is applied to the reading because if the CDN were perfect (without loss), the meter sensor 50 Ω impedance would see one-sixth ($50/300$) of the source voltage, or $20 \log 50/300$, which equals -15.56 dB. A correction factor of -107 dB was used for calculating the power level (dBm) (typical power meter display unit) developed across a 50 Ω impedance by a voltage level (dB μ V).

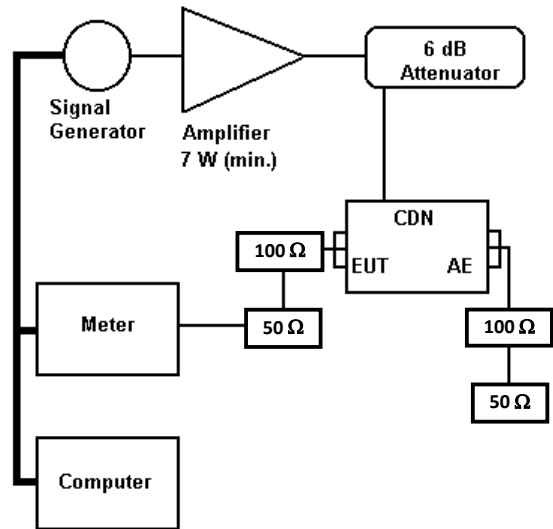


Figure 1—CDN level setting, -15.6 dB correction, $150\ \Omega$ (each side)

Table 1—Test level conversion table

Test level:	Meter reading ($50\ \Omega$ impedance):
1 V (emf)	$(120\text{ dB } \mu\text{V}) - (15.6\text{ dB}) - (107\text{ dB}) = -2.6\text{ dBm}$
3 V (emf)	$(130\text{ dB } \mu\text{V}) - (15.6\text{ dB}) - (107\text{ dB}) = +7.4\text{ dBm}$
10 V (emf)	$(140\text{ dB } \mu\text{V}) - (15.6\text{ dB}) - (107\text{ dB}) = +17.4\text{ dBm}$

The frequency is incremented in 1% steps, (next frequency = preceding frequency $\times$ 1.01) beginning at 150 kHz, and the drive level out of the signal generator (in dBm) is adjusted to give the power meter readings shown above (in dBm, up to 80 MHz or 230 MHz). This list of frequencies and signal generator output levels becomes the “drive table” played back by the computer (or manually adjusted) during the test run.

After completion of the “drive table,” the level-setting common-mode (shorting) adapters are removed from each side of the CDN and it is connected into the test setup as shown in Figure 2.

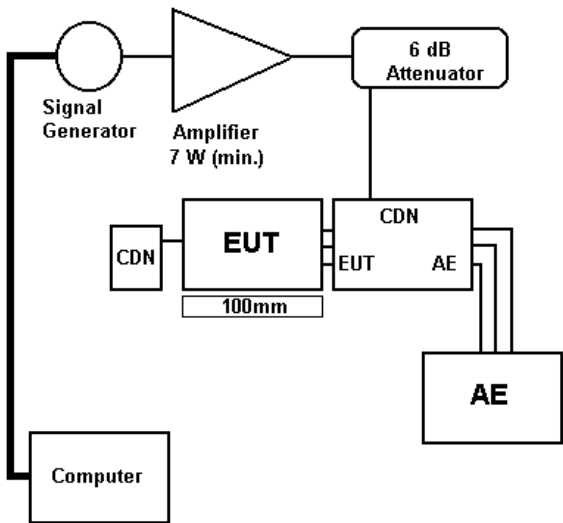


Figure 2—CDN run-test setup

Notice that the EUT is elevated 100 mm above the ground plane. EUT ports are to be fitted with CDNs and terminated according to the requirements of IEC 61000-4-6, so that the EUT is never RF-shorted to the ground plane, which can invalidate the test. The “drive table” for that CDN is then played back by the computer (or manually) with 1 kHz 80% AM modulation applied at each frequency, while the EUT is monitored for its performance criteria. Each CDN is driven with its own drive table sequentially.

5.3.2.3 Use of other coupling methods

If a CDN is not suitable and the line is shielded (screened), an “S” series CDN can be used if suitable. Direct injection (through the 100 Ω resistor) onto the shield (screen) of the cable under test may also be used. Separate decoupling with the ferrite decoupler is recommended.

If neither of these methods is suitable, clamp injection techniques are allowed. However, injected currents shall be monitored with a monitor current probe and spectrum analyzer for both the bulk current injection (BCI) probe (150 Ω and 50 Ω) as well as for the EM clamp (150 Ω) methods. The use of a ferrite decoupler to protect the AE is recommended for both clamp injection techniques. The test setup replicates the 150 Ω common mode impedance required and the functional installation conditions as closely as possible. To confirm that the common mode impedance of 150 Ω is realized, check that the following conditions are met:

- a) Each AE is placed on a 100 mm support above the ground plane and decoupled as required.
- b) All cables touching each AE use a ferrite decoupler and are kept 30 mm to 50 mm above the ground plane.
- c) Injection devices on each cable should be placed less than 30 cm from the EUT.
- d) CDNs for both the EUT and any AE are terminated as specified in IEC 61000-4-6.

The connection of the EM clamp for level-setting also uses an adapter and 150 Ω termination impedances on each side, as shown in Figure 3.

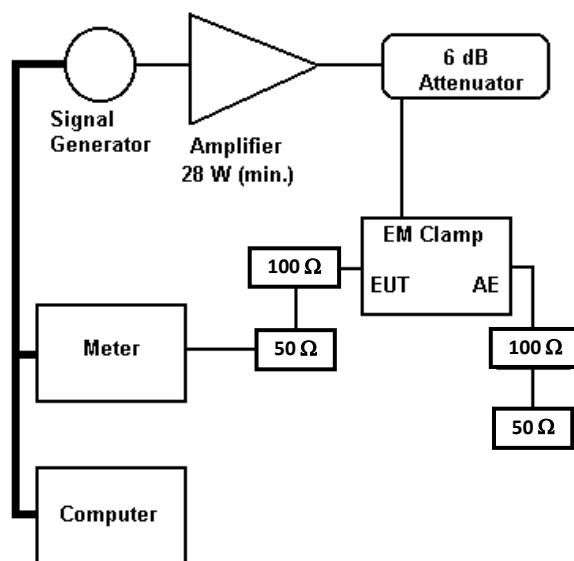
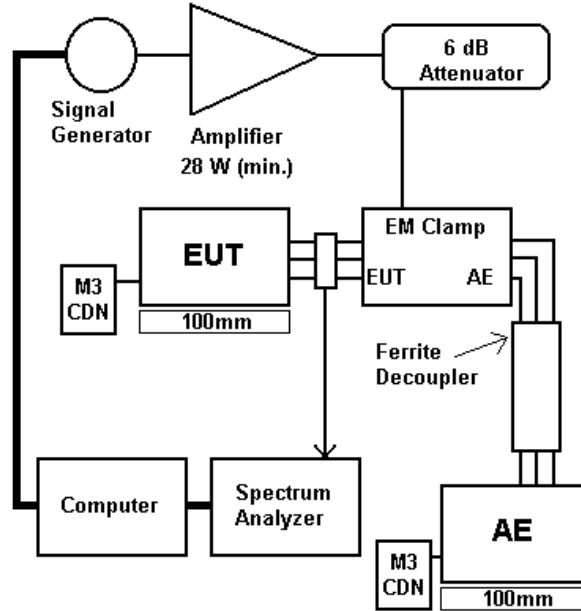


Figure 3—EM clamp level setting, −15.6 dB correction, 150 Ω (each side)

The power meter readings needed for setting the three test levels in the standard are the same as for CDNs and are shown in Table 1. After the level-setting procedure has been completed with the creation of the “drive table,” the adapters are removed, the EM clamp is opened, and the line under test is placed into the clamp. The cover is closed and the equipment is connected as shown in Figure 4.



NOTE—The ferrite decoupler shown is optional and is used only if required to assure that the AE remains unperturbed during the testing. M3 refers to a three-wire CDN, as described in IEC 61000-4-6.

Figure 4—EM clamp run-test setup

Notice that the EUT and AE are both elevated 100 mm above the ground plane, and all EUT and AE ports are to be fitted with terminated CDNs. This is to keep any line from shorting the EUT to ground and invalidating the testing. The “drive table” is played back by the computer with 80% AM modulation applied, and the EUT is monitored for its performance criteria. During the test, the injected current is monitored with a monitor current probe and spectrum analyzer to preclude exceeding $I(\text{max})$. $I(\text{max})$ is the short-circuit current from a $150\ \Omega$ source, and equals $V(\text{emf}) / 150\ \Omega$, as shown in Table 2. If this level is exceeded during the test, the output level from the signal generator is reduced until $I(\text{max})$ is achieved, and a notation of the reduced generator output (in dBm) is made in the test report. After an appropriate dwell time, the frequency is incremented, the computer resumes playing back the “drive table,” $I(\text{max})$ is again monitored, and the testing continues while the EUT is monitored for its performance criteria.

Table 2—Test level conversion table

Test level	$I(\text{max})$ (mA)	$I(\text{max})$ (dB μA)
1	$1\ 000\ \text{mV} / 150\ \Omega = 6.67\ \text{mA}$	$20\ \log(6667\ \mu\text{A} / 1) = 76\ \text{dB}\mu\text{A}$
2	$3\ 000\ \text{mV} / 150\ \Omega = 20\ \text{mA}$	$20\ \log(20\ 000\ \mu\text{A} / 1) = 86\ \text{dB}\mu\text{A}$
3	$10\ 000\ \text{mV} / 150\ \Omega = 66.67\ \text{mA}$	$20\ \log(66\ 667\ \mu\text{A} / 1) = 96\ \text{dB}\mu\text{A}$

5.3.3 Suggested immunity level

For military testing, the suggested immunity level is shown in Curve 3 of Figure CS114-1 of MIL-STD-461G-2015. The calibration level is 49 dB μA (282 μA) at 10 kHz increasing to 89 dB μA (28 mA) at 1 MHz to 30 MHz and decreasing linearly to 77 dB μA (7 mA) at 400 MHz. The induced current limit is 95 dB μA during test.

For commercial testing, the suggested immunity level is Level 3 or 10 V (emf) (open circuit). In either case, the performance of the EUT is evaluated against the performance criteria during and after the testing.

5.4 Communications receiver antenna input immunity (receivers other than broadcast), 30 Hz to 10 GHz

5.4.1 General

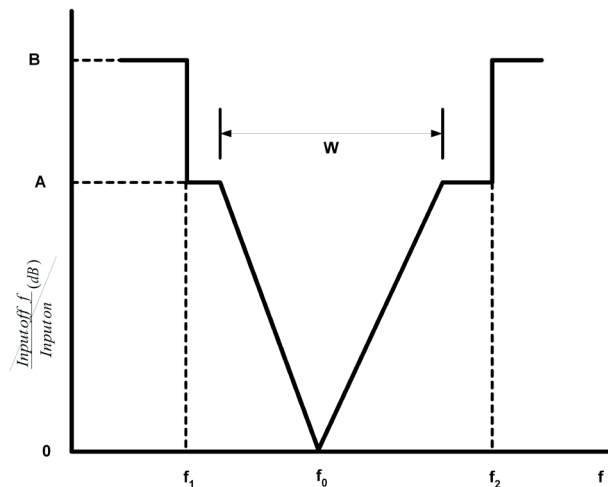
This test method is applicable for determining the immunity or front-end rejection of receivers operating in the frequency range 30 Hz to 10 GHz.

NOTE—Methods CS103, CS104, and CS105 of MIL-STD-461G-2015 can be used to select other conducted immunity tests.

5.4.2 Immunity signal

The EUT should be subjected to the signal levels as shown in Figure 5. Concerning Figure 5, note the following:

- The limit at A is 80 dB above the input level required to produce the standard reference output. The standard reference output should be specified for this test. A possible standard reference might be an output that produces 30 dB quieting, or 10 dB signal (S) plus noise (N) plus distortion (D) divided by noise plus distortion [i.e., $(S + N + D)/(N + D)$].
- The limit at B should be 0 dBm applied directly to the receiver input terminals. Caution is advised that 0 dBm might be too severe for certain receivers. For example, a receiver with a sensitivity of 1 mV requires 107 dB of rejection outside the tuning band, which is a severe requirement.



- f_0 Receiver-tuned frequency
- f_1 Lowest tunable frequency of receiver band in use
- f_2 Highest tunable frequency of receiver band in use
- w Bandwidth between 80 dB points of the receiver selectivity curve, as specified in the test sample technical requirements or the control plan

Figure 5—Test signal definitions

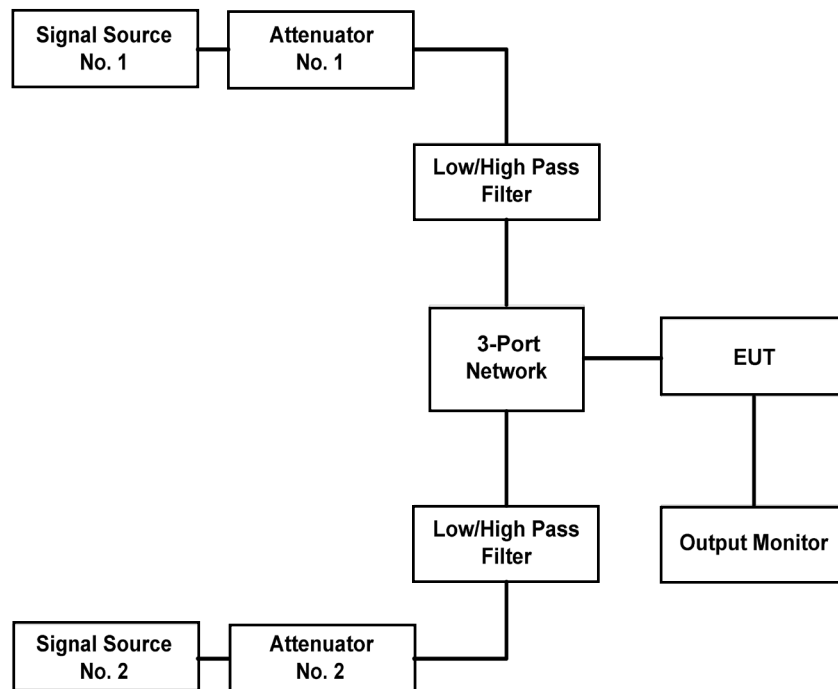


Figure 6—Communications receiver antenna input immunity general test setup

5.4.3 Test setup and procedure

The following steps should be used as a test procedure:

- a) Use the general setup as shown in Figure 6. With the EUT operating and Signal Source No. 2 turned off, tune Signal Source No. 1 to f_0 , which should be the receiver-tuned frequency.
- b) Adjust the output of Signal Source No. 1 to produce the standard reference output at the receiver.
- c) Record the un-modulated output level and frequency of Signal Source No. 1.
- d) Set the modulation for Signal Source No. 1 so as to produce the standard reference output as required by the receiver specification.
- e) Repeat steps a) through d) using Signal Source No. 2 with Signal Source No. 1 switched off.
- f) For the remainder of the test, have Signal Source No. 1 on and modulated as in step d), and have Signal Source No. 2 on but unmodulated.
- g) Set Signal Source No. 1 with its proper modulation to the frequency and level as initially determined and set Signal Source No. 2, with no modulation, to the levels shown in Figure 1.
- h) The frequency limits are such that the lowest test frequency should be the lower of $IF/5$ or $0.05 f_0$, where IF is the receiver intermediate frequency and f_0 is the receiver-tuned frequency. For multiple conversion receivers, select the lowest IF .
- i) The highest frequency for this test should be the higher of $5 \times f_{LO} + IF$ or $20 f_0$ (but less than 10 GHz) where f_{LO} is the receiver local oscillator frequency, f_0 is the receiver-tuned frequency, and IF is the receiver intermediate frequency.
- j) For multiple conversion receivers, the f_{LO} and IF should be the highest frequencies associated with the receiver.
- k) For receivers with waveguide input, the lowest test frequency should be $0.8 f_{CO}$ where f_{CO} is the waveguide cut-off frequency.

- l) Note that the frequency range defining the 80 dB selectivity points (w in Figure 5) is exempt from this test.
- m) While scanning the required frequency range with Signal Source No. 2, note any receiver responses.
- n) Check to make sure that the response noted is a spurious one and not due to an intermodulation product. Reducing the level of Signal Source No. 1 to see if the response disappears can do this check. If it does not disappear, then it is a true spurious response.
- o) After determining that a true spurious response has been found, return Signal Source No. 1 to its original level and reduce the level of Signal Source No. 2 until the receiver standard reference output is obtained. The difference, in dB, between this level on Signal Source No. 2 and the level determined initially on Signal Source No. 2 at the receiver-tuned frequency, is the spurious response rejection.
- p) Record frequency and level of Signal Source No. 2.

Signal Source No. 1 should be modulated in the same manner as specified in the section pertaining to receiver sensitivity measurements of the detailed equipment specification. When the equipment specification does not define this, the following should be used:

- AM receivers: The signal generator should be 80% modulated by a 1 kHz sine wave.
- SSB and FM receivers: The signal generator should be unmodulated.
- Pulse receivers: The modulation pulse should be adjusted so that 80% of its spectral energy lies within the 3 dB bandwidth of the receiver.

The signal generators emit a substantial amount of harmonics and other spurious energy. Care should be taken not to mistake an emission of the generator falling on f_0 for a spurious response of the equipment. It is possible to have spurious responses at $f_0/2$, $f_0/3$, $f_0/4$, etc. that are not due to generator harmonics. To guard against the effects of signal generator harmonics, it is necessary to use high- and low-pass filters as necessary throughout the test.

A suitable test for receiver image frequency rejection might be appropriate.

5.4.4 Performance criteria

The pass/fail criterion for this test is that the EUT should demonstrate the front-end receiver rejection of undesired signals as specified in Figure 5.

5.4.5 Test equipment

The test equipment required to perform this test is as follows:

- a) Signal generator (two might be required)
 - 1) Frequency range: 10 kHz to 10 GHz
 - 2) Frequency accuracy: $\pm 1\%$
 - 3) Output voltage range: Standard reference output to +80 dB
 - 4) Harmonic and spurious signal: more than 30 dB down from fundamental. External filtering might be needed to meet this requirement.
 - 5) Modulation characteristics: FM, CW, AM to 1 GHz, pulse above 200 MHz
- b) Low-pass and high-pass filters (to remove signal generator harmonics as required)
 - 1) Impedance: 50 Ω
 - 2) Power rating: 1 W or greater

- c) Power splitters (three-port network)
 - 1) Frequency range: dc to 10 GHz (several types might be required across the frequency range)
 - 2) Insertion loss: <6 dB
 - 3) Impedance: 50 Ω
 - 4) Power rating: 1 W or greater
- d) Attenuators (two required, one each at output of signal sources)
 - 1) Frequency range: dc to 10 GHz
 - 2) Impedance: 50 Ω
 - 3) Power rating: 1 W or greater
 - 4) Attenuation: 10 dB

5.5 Receiver antenna input immunity for TVs and VCRs, 0.5 MHz to 30 MHz

5.5.1 General

The purpose of this test is to demonstrate that the TV or VCR is immune to signals other than the intended signal at its RF input terminals.

5.5.2 Test procedure

Use the test procedures given in CTA-544-C, CTA CEA/IS-31, and CTA CEA/IS-16-A. Recommended test equipment is listed in B.3.

5.6 Power/interconnection-line surge voltage immunity

5.6.1 General

The purpose of this test is to determine if the EUT is immune to high-energy disturbances on power-lines and interconnecting power-lines as a result of transients caused by switching systems or lightning.

5.6.2 Test procedure

Use the test procedure given in IEC 61000-4-5. Recommended test equipment is listed in B.4.

5.6.3 Suggested immunity level

The suggested immunity level can be selected from Table 3. All the test levels below the suggested level should also be tested. The suggested level for power-lines is 1 kV line-to-line and 2 kV lines to protective earth (PE). Signal and control lines are generally not surge tested.