

American National Standard for Compliance Testing of Transmitters Used in Licensed Radio Services

C63[®]

Accredited Standards Committee C63[®]—Electromagnetic Compatibility

Accredited by the
American National Standards Institute

IEEE
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USA

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American National Standard for Compliance Testing of Transmitters Used in Licensed Radio Services

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 standard is intended to cover procedures for compliance testing of a wide variety of transmitters designed to operate in licensed radio services, including but not limited to: Commercial Mobile Radio Services, Public Mobile Services, Cellular Radiotelephone Service, Personal Communication Services, Miscellaneous Wireless Communication Services, Private Land Mobile Radio Services, and Personal Radio Services. Tests methods are provided for measurement of radiated and conducted emissions, RF power, out-of-band emissions, frequency stability, and other regulatory requirements for a variety of devices. This standard does not consider test methods for requirements specific to maritime and aviation transmitters, ground-based radars, satellite equipment, fixed microwave equipment, or broadcast transmitters. The latter equipment may be covered in future revisions of this standard.

Keywords: ANSI C63.26, compliance testing, frequency stability, licensed radio services, licensed transmitters, out-of-band emissions, radiated and conducted emissions, RF power, test procedures

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Introduction

This introduction is not part of ANSI C63.26-2015, American National Standard for Compliance Testing of Transmitters Used in Licensed Radio Services.

ANSI C63.26 is a standard for compliance testing of transmitters operated in certain licensed radio services. This consensus standard specifies methods, instrumentation, and facilities requirements for the compliance testing of a wide variety of radio transmitters designed to operate in licensed radio services. It does not include limits or station licensing requirements. Tests methods are provided for measurement of radiated and conducted emissions, RF output power, out-of-band emissions, frequency stability, and other regulatory requirements for a variety of devices. This standard does not consider test methods for requirements specific to maritime and aviation transmitters, ground based radars, satellite communication equipment, fixed microwave equipment, or broadcast transmitters. This equipment may be covered in future revisions of this standard. In addition, this standard does not include evaluation methods for transmitters subject to regulatory requirements concerning human exposure to RF energy; RF exposure conformity assessment methods are given in other standards. This standard serves as a companion standard to ANSI C63.10 for compliance testing of unlicensed wireless devices, and ANSI C63.4 for compliance testing of low-voltage electrical and electronic equipment.

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1. Overview

1.1 Scope

This consensus standard specifies methods, instrumentation, and facilities requirements for the compliance testing radio transmitters designed to operate in a licensed radio service. It does not include limits or licensing requirements. Tests methods are provided for measurement of radiated and conducted emissions, RF output power, out-of-band emissions, frequency stability, and other regulatory requirements for a variety of devices, as described in this standard. This standard does not consider test methods for requirements specific to maritime and aviation transmitters, ground based radars, satellite communication equipment, fixed microwave equipment, and broadcast transmitters.¹ The latter equipment types may be covered in future revisions of this standard. In addition, this standard does not include evaluation methods for transmitters subject to regulatory requirements concerning human exposure to RF energy; RF exposure conformity assessment methods are given in other standards, e.g., IEEE Std 1528™-2013 [B41].² Other documents covering a limited number of the test procedures included in this standard are available and may be used at the discretion of the regulatory authority, e.g., IEEE Std 377™-1980 [B36], TIA-102.CAAA-D [B62], TIA 603-D-2010 [B63].

¹ Test methods for additional requirements applicable to some transmitters are given in other ASC C63® documents, e.g., ANSI C63.19-2011 [B3] for hearing aid compatibility of wireless communications devices.

² Numbers in brackets correspond to the numbers in the bibliography in Annex K.

This document provides standard test methods for determining compliance with regulatory requirements for many types of transmitters used in the various licensed radio services. Procedures for these transmitters include but are not limited to the following radio services:¹

- a) Commercial Mobile Radio Services (CMRS)
- b) Public Mobile Services
- c) Cellular Radiotelephone Service
- d) Personal Communication Services (PCS)
- e) Miscellaneous Wireless Communication Services
- f) Private Land Mobile Radio Services (PLMRS)
- g) Personal Radio Services (PRS)
- h) Public Safety Radio Pool (previously known as Public Safety Radio Service)

Clause 2 and Clause 3 contain the normative references and definitions used in this standard, respectively. Clause 4 provides the specifications for the necessary test instrumentation needed for performing compliance testing. Clause 5 provides standard test methods for most licensed radio services, and Clause 6 identifies additional tests or procedures for specific radio transmitters. Clause 7 specifies the test procedures for RF repeaters, amplifiers, and signal boosters. Clause 8 specifies requirements for reporting test results.

Fourteen informative annexes provide the following additional information:

- Annex A (*informative*)—Sample test report template
- Annex B (*informative*)—Pre-test site path loss characterization for determining radiated emissions
- Annex C (*informative*)—Guidelines for determining equivalent ERP and EIRP
- Annex D (*informative*)—Broadband measurement discussion
- Annex E (*informative*)—Consumer signal boosters authorized frequency bands
- Annex F (*informative*)—Guidelines for determining the mobile station coupling loss (MSCL)
- Annex G (*informative*)—Wideband consumer booster noise limits
- Annex H (*informative*)—Provider-specific consumer booster noise and gain limits
- Annex I (*informative*)—Examples of out-of-band emission masks
- Annex J (*informative*)—Glossary
- Annex K (*informative*)—Bibliography and selected source material

Use of the applicable clauses to transmitters under test, allows users of this standard to determine compliance of a device to national regulatory requirements.² The annexes provide additional informative material. However, any test procedure identified for use by the national regulatory authority that differs from the provisions of this standard shall take precedence.

Numbered cross-references used throughout this standard refer to either a specific subclause of this standard; for example, 6.2 refers to subclause 6.2, and A.2 refers to subclause A.2 of Annex A.

¹ These radio services are based on the FCC Rules and Regulations in U.S. Code of Federal Regulations, Title 47—Telecommunication, Parts 0–199, of the United States; see also (<http://wireless.fcc.gov/services/>). Other countries will have similar rules and regulations to promote radio communications, but the radio services can be called by different names.

² Information with respect to the application of the regulatory requirements to specific test procedures can be found on the FCC and IC websites.

In this document, the word *shall* is used to indicate a mandatory requirement. The word *should* is used to indicate a recommendation. The word *may* is used to indicate a permissible action. The word *can* is used for statements of possibility and capability. Tolerances on dimensions and distances are based on good engineering practice where not specified. In this standard, the text takes precedence over the figures because the text is complete and the figures are illustrative of a typical application of the text. Notes are used in the text for emphasis or to offer informative suggestions about the technical content of the standard, and provide additional information to assist the reader with a particular passage, but they do not include mandatory requirements. Footnotes in text are included only for information, clarification, and/or aid applicable to the use of the standard. Mandatory requirements are not included in footnotes.

Measurement methods are provided for radiated and conducted emissions that can be generated by a variety of devices, as described in 1.2. Definitions are provided for terms and phrases that do not represent obvious or common usage. In most cases, measurement instrumentation and calibration requirements are only generally characterized in deference to standards dedicated to these subjects, which should be used in conjunction with this standard. Requirements for operation of test samples during measurements are presented for devices in general, as well as for specific types of devices that are frequently measured. Specific requirements for emission test data recording and reporting are presented with reference to general requirements contained in documents dedicated to standard laboratory practices, which should be used in conjunction with this standard. The main text is augmented by a series of annexes that provide details for certain measurement methods and facilities.

1.2 Purpose

A wide variety of transmitters are intended to be operated in the licensed radio services which are subject to regulatory requirements. The primary way to show compliance in meeting regulatory requirements is by testing such devices in a repeatable and reproducible manner. This standard presents the methods of measurement to show compliance with the technical specifications for the majority of present transmitters as identified in 1.1. It represents a consolidation and elucidation of procedures that were heretofore dispersed throughout a number of documents, which caused confusion regarding where to find the appropriate test method. It is not expected that all of the transmitters on the market will in fact be covered by this standard. Also, as new measurement methods mature, this standard will be amended or a follow-up standard developed to present new methods. It is also expected that the ASC C63[®] committee that developed this standard can provide a forum for test laboratories, manufacturers, and regulatory authorities to determine the need for additions and amendments of this standard to accommodate new wireless devices in the future.

1.3 Measurement uncertainty

The results of measurements of emissions from licensed transmitters shall include measurement instrumentation uncertainty considerations contained in ETSI TR 100 028-1 (2001-12) and ETSI TR 100 028-2 (2001-12).³ In cases where quasi-peak measurements are made, use ANSI C63.23. Determining compliance shall be based on the results of the compliance measurement, not taking into account measurement instrumentation uncertainty. However, the measurement uncertainty of the measurement instrumentation and its associated connections between the various instruments in the measurement chain shall be calculated, and both the measurement results and the calculated measurement uncertainty shall appear in the test report.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

³ Information on references can be found in Clause 2.

ANSI C63.2, American National Standard for Electromagnetic Noise and Field Strength Instrumentation, 10 Hz to 40 GHz—Specifications.⁴

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

ANSI C63.10, 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 C63.23, American National Standard Guide for Electromagnetic Compatibility—Computations and Treatment of Measurement Uncertainty.

ETSI TR 100 028-1 V1.4.1 (2001-12), Electromagnetic Compatibility and Radio Spectrum Matters (ERM); Uncertainties in the Measurement of Mobile Radio Equipment Characteristics; Part 1.⁵

ETSI TR 100 028-2 V1.4.1 (2001-12), Electromagnetic Compatibility and Radio Spectrum Matters (ERM); Uncertainties in the Measurement of Mobile Radio Equipment Characteristics; Part 2.

3. Definitions and acronyms

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* and ANSI C63.14 should be consulted for terms not defined in this clause.⁶ Definitions in wireless device product standards or regulations shall take precedence where applicable. See also the Glossary provided in Annex J, which includes various terms relevant for wireless devices compiled from FCC, ITU, and other documents.

additive white gaussian noise (AWGN): The statistically random radio noise having a frequency spectrum that is continuous and uniform over a specified frequency band. White noise has equal power per hertz over the specified frequency band.

adjacent channel power (ACP): The ratio of the average power in the adjacent frequency channel to the average power in the transmitted frequency channel, and is usually measured at multiple offsets. (FCC-05-9 [B19])

authorized commercial mobile radio service (CMRS) provider signal: This is the CMRS Provider's downlink signal that is generated by the base station simulator that represents the authorized licensee's base station signal for provider-specific boosters to determine the appropriately licensed spectrum blocks of operation. For example, a 3rd Generation Partnership Project (3GPP) universal mobile telecommunications system base station signal will contain the licensee's unique public land mobile network identification code.

⁴ C63® publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>) or from the American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

⁵ ETSI publications are available from the European Telecommunications Standards Institute, 650, Route des Lucioles, 06921 Sophia-Antipolis Cedex, FRANCE (<http://www.etsi.org/>).

⁶ *IEEE Standards Dictionary Online* is available at: <http://ieeexplore.ieee.org/xpls/dictionary.jsp>.

automatic gain control (AGC): A circuit that automatically controls the gain of a signal by applying more gain to weaker received signals and less (or no) gain to stronger received signals.

band edge emission: A “channel edge emission” with the nominal center frequency of the channel adjusted as close to the band edges, both upper and lower successively, as the equipment design permits.⁷

base station coupling loss (BSCL) dependent region: The region within gain limits where the permitted gain varies with and is dependent on the BSCL parameter.⁸

base station coupling loss (BSCL): The coupling loss (in dB) between the donor port of the consumer booster and the input port of the base station. BSCL can be determined in three ways.⁹

bin size: Frequency span divided by the number of trace points minus one on an instrument display.

block edge emission: Emissions at the edge of a specified frequency block in allocated bands for certain radio services. A “block edge limit,” also known as “emission mask,” is an in-band (and/or in-block) out-of-channel emission limit. A “block edge emission” is a “channel edge emission” with the nominal center frequency of the channel adjusted as close to the band edges, both upper and lower successively, as the equipment design permits.¹⁰

broadband emission: RF signal with an occupied bandwidth (OBW) wider than the resolution bandwidth (RBW) of the measuring instrument that is to be used for measurement.

calibration: (A) The comparison of measuring and test equipment (M&TE) or measurement standard of unknown accuracy to a measurement standard of known accuracy in order to detect, correlate, report, or eliminate by adjustment any variation in the accuracy of the instrument being compared. (B) The set of operations that establish, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known values of a measurand. (ISO/IEC 17025:2005 [B45]) (C) Operation establishing the relation between quantity values provided by measurement standards and the corresponding indications of a measuring system, carried out under specified conditions and including evaluation of measurement uncertainty. (ANSI C63.10)

code division multiple access (CDMA): A method for transmitting multiple digital signals simultaneously over the same carrier frequency or channel.

consumer signal booster: A bidirectional signal booster that is marketed and sold to the general public for use without modification, installed without third-party assistance and operated only with approved antennas, cables, and/or coupling devices as specified by the booster manufacturer.

continuous transmit mode: A mode in which the transmitter is continuously transmitting at a $\geq 98\%$ duty cycle. (ANSI C63.10)

continuous wave (CW): An electromagnetic wave of constant amplitude and frequency; and in mathematical analysis, of infinite duration. Can also refer to a data modulation scheme in which the data is represented by a carrier signal being switched on and off.

direct radiated field strength method: An alternative to the traditional two-stage radiated substitution procedure for every emission. The path loss of the test site as a function of frequency is pre-characterized, then this pre-characterized path loss is added to a direct radiated measurement of the equipment under test (EUT) to yield the radiated power of the emission.

⁷ See Annex I.

⁸ See Annex H.

⁹ See 47 CFR 20.21(e)(9)(i)(C)(1)(ii).

¹⁰ See Annex I.

emission bandwidth (EBW): A specification of the regulatory authority. It is defined as the width of the signal between two points, one below the carrier center frequency and one above the carrier center frequency, that are 20 dB or 26 dB down relative to the maximum level of the modulated carrier.

equipment under test (EUT): A device or system being evaluated for compliance that is representative of a product to be marketed.

equivalent isotropically radiated power (EIRP): (A) In a given direction, the gain of a transmitting antenna multiplied by the net power accepted by the antenna from the connected transmitter. (*IEEE Standards Dictionary Online*) (B) The product of the power of an emission as supplied to an antenna and the antenna gain in a given direction relative to an isotropic antenna. (MIL-STD-463A [B52])

NOTE—See also **effective isotropically radiated power** in the *IEEE Standards Dictionary Online*.

fixed consumer signal booster: A consumer signal booster designed to be operated in a fixed location in a building.

floor standing device: Equipment designed to be used directly in contact with the floor or supported above the floor on a surface designed to support both the equipment and the operator (e.g., a raised computer floor). (ANSI C63.4)

harmonic emissions: Electromagnetic radiation from a transmitter or local oscillator that is not part of the information signal, but has a frequency that is an integral multiple of the carrier frequency. (ANSI C63.14) (MIL-STD-463A [B52])

industrial signal booster: All signal boosters other than consumer signal boosters. The industrial signal booster classification thus covers a wide variety of devices that are designed for installation by licensees or qualified installers. This industrial signal booster classification also includes signal boosters deployed in the private land mobile radio (PLMRS) bands by licensees or those with the consent of PLMRS licensees.

licensed radio service: A radio service such as mobile telephone, business radio, cellular telephone, etc., which operates with a blanket or individual license.

licensed transmitter: A transmitter authorized to operate under one of the licensed radio services and is either individually licensed or operates under a blanket license authorized under a specific radio service.

licensee frequency block: A frequency range assigned to a licensee contained within a licensed radio service band. Most CMRS bands are divided into multiple licensee frequency blocks.

long-term evolution (LTE): A standard for wireless communication of high-speed data for mobile phones and data terminals.

measurement antenna: The receive antenna used to measure the radiated emissions emanating from a substitution antenna and the equipment under test (EUT) during substitution method testing, or to measure radiated emissions during field strength testing.

measurement bandwidth: The bandwidth which is technically appropriate for the measurement of a specific system. In common spectrum analyzers this is generally referred as the resolution bandwidth (RBW). (ITU-R SM.1541-5:2013 [B48], 1.7) *See also:* **reference bandwidth**.

NOTE—The measurement bandwidth may differ from the reference bandwidth, provided the results can be converted to the required reference bandwidth.

mobile consumer signal booster: A consumer signal booster designed to operate in a moving vehicle where both uplink and downlink transmitting antennas are at least 20 cm from the user or any other person.

mobile station coupling loss (MSCL): The minimum inside coupling loss (in decibels) between the wireless device and the input (server) port of the consumer booster.¹¹

narrowband emission: RF signals with an occupied bandwidth (OBW) smaller (narrower) than the resolution bandwidth (RBW) of the measuring instrument that is to be used for measurement.

network protection standard (NPS): Specifies technical, operational, and registration requirements designed to reduce the potential for consumer signal boosters to cause interference to wireless networks.¹²

non-authorized commercial mobile radio service (CMRS) provider signal: A downlink signal that is generated by the base station simulator that represents a non-authorized licensee's base station signal. For example, a 3rd Generation Partnership Project (3GPP) universal mobile telecommunications system base station (3GPP UMTS) base station signal will contain another licensee's unique public land mobile network (PLMN) identification code.

occupied bandwidth (OBW): The width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage $\beta/2$ of the total mean power of a given emission. Unless otherwise specified by the ITU-R Recommendation for the appropriate class of emission, the value of $\beta/2$ should be taken as 0.5%. (NTIA Manual [B54])

NOTE—See also **occupied bandwidth (radio noise emissions)** in the *IEEE Standards Dictionary Online*.

open-area test site (OATS): A site for electromagnetic measurements that has a reflective ground plane and is open, flat terrain at a distance far enough away from buildings, electric lines, fences, trees, underground cables, pipelines, and other potential reflective objects, so that the effects due to such objects are negligible.

NOTE—Requirements for acceptability and construction of OATS are called out in ANSI C63.4 and ANSI C63.7, respectively.

out-of-band domain (of an emission): The frequency range, immediately outside the necessary bandwidth but excluding the spurious domain, in which out-of-band emissions generally predominate.

out-of-band emission (OOBE): (A) Emission of a frequency or frequencies outside a specified frequency range. (B) Emission on a frequency or frequencies immediately outside the necessary bandwidth that results from the modulation process, but excluding spurious emissions. (ITU Radio Regulations [B46])¹³

out-of-channel block: Also known as out-of-block emissions, are any unwanted emissions from a transmit channel contained within the licensee frequency block which are immediately outside the licensee assigned block.

peak transmit power: (A) (P_{EUT}) The peak power output observed over an interval of time equal to the transmission burst duration of the equipment under test (EUT) under all conditions of modulation. (ANSI C63.17 [B2]) (B) Power measured with the peak detector using a filter with width and shape of which is sufficient to accept the signal bandwidth. (ANSI C63.10)

NOTE—*Peak power* is synonymous with *peak transmit power*. (ANSI C63.10)

pole/tower mount device: A device designed to be installed and normally operated on a pole or tower, e.g., repeater, booster.

provider-specific consumer signal booster: A consumer signal booster that may only operate on the frequencies and in the market areas of the specified licensee(s).¹⁴

¹¹ See Annex F.

¹² See 47 CFR 20.21(e)(8) for wideband consumer signal boosters NPS and 47 CFR 20.21(e)(9) for provider-specific (frequency-selective) consumer signal boosters NPS.

¹³ Radio regulatory authorities use the definition in (B) for OOBE requirements.

pseudorandom binary sequence (PRBS): A fixed-length, mathematically-randomized sequence of bits that satisfies many of the criteria for a true random sequence and thus is frequently used in digital functionality testing.

rack mount device: A device designed to be installed and normally operated in a rack which can be either floor standing or table top device.

NOTE—An example of a rack mount device is a base station amplifier module (the term module here means an assembly of interconnected components that constitutes an identifiable device, instrument, or piece of equipment).

received signal power level within channel (RPCH)-dependent region: The region within gain limits, where the permitted gain varies with and is dependent on the downlink RPCH parameter.¹⁵

received signal power level within channel (RPCH) for provider-specific consumer boosters: The total received signal power level within the authorized downlink channel in dBm referenced to the consumer booster's donor port. This parameter is applicable to gain limits.¹⁶

received signal strength indication (RSSI)-dependent region: The region within applicable noise and gain limits where the permitted noise and gain varies with and is dependent on the downlink RSSI parameter.¹⁷

received signal strength indication (RSSI) for wideband consumer boosters: The downlink composite received signal power in dBm, referenced to the consumer booster's donor antenna port, for all CMRS base stations' signals received within the band of operation.¹⁸

reference bandwidth: The bandwidth required for uniquely defining the out-of-band domain emission limits. If not explicitly given with the out-of-band domain emission limit, the reference bandwidth should be 1% of the necessary bandwidth. [ITU-R SM.1541-5:2013 [B48], 1.6] *See also:* **measurement bandwidth**.¹⁹

repeater: A device that re-transmits a signal to another station. Repeaters are different from boosters in that they can include frequency conversion. These devices are typically single channel but can also be multiple channels.

signal booster: A device that automatically receives, amplifies, and retransmits on a bidirectional or unidirectional basis; the signals received from base, fixed, mobile, or portable stations, with no change in frequency or authorized bandwidth.

signal-plus-noise-plus-distortion to noise-plus-distortion (SINAD) ratio: A measurement that can be used to examine the degradation of the signal by unwanted or extraneous signals, including noise and distortion, and is summarized as the ratio of the total signal power level (signal + noise + distortion) to the unwanted signal power (noise + distortion).

smart antenna system: A system that combines multiple antenna elements with a signal-processing capability to optimize its radiation and/or reception pattern automatically in response to the signal environment.

NOTE—The two major categories of smart antennas, based on the choice of transmit strategy, are adaptive antennas and switched-beam antennas.

¹⁴ In the U.S., provider-specific consumer signal boosters may only be certificated and operated with the consent of the licensee(s) whose frequencies are being amplified by the device.

¹⁵ See Annex H.

¹⁶ See 47 CFR 20.21(e)(9)(i)(C)(1)(ii).

¹⁷ See Annex G and Annex H for wideband and provider-specific consumer signal boosters, respectively.

¹⁸ See applicable noise limits in 47 CFR 20.21(e)(8)(i)(A)(1) and gain limits in 47 CFR 20.21(e)(8)(i)(C)(1)(i).

¹⁹ See Annex I.

spectrum block filtering: Wideband consumer booster filtering, rejection, or attenuation to one or more spectrum blocks within a commercial mobile radio service band (e.g., a wideband consumer booster supporting the Cellular A band, with filtering that attenuates or blocks the Cellular B band spectrum).

spurious domain (of an emission): The frequency range beyond the out-of-band domain in which spurious emissions generally predominate.

spurious emission: Any electromagnetic emission at a frequency or frequencies that are outside the range of the necessary emission bandwidth, the level of which may be reduced without affecting the corresponding transmission of information. *Spurious emissions* include parasitic emissions and intermodulation products but exclude emissions in the immediate vicinity of the necessary emission bandwidth that are a result of the modulation process and are necessary for the transmission of information. Harmonic emissions are considered to be *spurious emissions*. (MIL-STD-463A [B52])

substitution antenna: The transmit antenna used during the substitution method for radiated emissions which duplicates the signals observed to be emanating from the equipment under test (EUT).

system: (A) A composite of equipment, subsystems, skilled personnel, and techniques capable of performing or supporting a defined operational role. A complete *system* includes related facilities, equipment, subsystems, materials, services, and personnel required for its operation to the degree that it can be considered self-sufficient within its operational or support environment (MIL-STD-464C [B53]) (B) A configuration of interconnected devices, including accessories and peripherals, and their cables, which is designed to perform a particular function or functions. (ANSI C63.4, ANSI C63.10)

tabletop device: A device designed to be placed and normally operated on the raised surface of a table, e.g., most personal computers. (ANSI C63.4, ANSI C63.10)

test equipment: Equipment that is intended primarily for purposes of performing measurements or scientific investigations. Such equipment includes, but is not limited to, field strength meters, spectrum analyzers, and modulation monitors.

NOTE—Test equipment products that also contain unlicensed wireless device and/or licensed transmitter component(s) and/or function(s) are generally subject to applicable radio regulatory requirements.

transmitted noise power level: The noise power level measured at the signal booster output that is represented by the sum of the thermal noise power, the booster noise figure, and the booster gain, and any additional noise generated by the booster expressed in dBm within a 1 MHz bandwidth (dBm/MHz).

unwanted emissions: Emissions that consist of spurious and out-of-band emissions. (ITU Radio Regulations [B46])

wideband consumer signal booster: A consumer signal booster that may operate on the frequencies and in the market areas of multiple licensees.

3.2 Acronyms

3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2
AGC	automatic gain control
ANSI	American National Standards Institute
ASC	Accredited Standards Committee
AWGN	additive white gaussian noise
AWS	Advanced Wireless Service
BSCL	base station coupling loss
C4FM	continuous four level FM
CCDF	complimentary cumulative distribution function
CDMA	code division multiple access

CFR	U.S. Code of Federal Regulations
CISPR	International Special Committee on Radio Interference (under auspices of the IEC)
CMRS	Commercial Mobile Radio Service
CQPSK	compatible quadrature phase-shift keying
CW	continuous wave
DMM	digital multi-meter
DOP	demodulator output port
EBW	emission bandwidth
EIRP	equivalent isotropically radiated power
EMC	electromagnetic compatibility
ERP	effective radiated power
EUT	equipment under test
FCC	Federal Communications Commission
FM	frequency modulation
GPS	Global Positioning System
GSM	Global System for Mobile Communication
H-CPM	harmonized continuous phase modulation
IC	Industry Canada
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IF	intermediate frequency
ITU-R	International Telecommunications Union-Radio
KDB	Knowledge Database (FCC/OET)
LPDA	log periodic dipole array
LTE	Long-Term Evolution
MIMO	multiple input multiple output
NIST	National Institute of Standards and Technology
NPS	Network Protection Standard (consumer boosters)
OATS	open-area test site
OBW	occupied bandwidth
OET	Office of Engineering and Technology (FCC)
PAPR	peak-to-average power ratio
PCS	Personal Communication Service
PDCF	pulse desensitization correction factor
PLMN	public land mobile network
PLMRS	Private Land Mobile Radio Services
PM	phase modulation
PPSD	peak power spectral density
PRBS	pseudorandom binary sequence
PRS	Personal Radio Services
PSD	power spectral density
QP	quasi-peak
QPD	quasi-peak detector
RBW	resolution bandwidth
RF	radio frequency
RNSS	Radio Navigation Satellite Service
RPCH	received power within channel
RSSI	received signal strength indication
SINAD	signal-plus-noise-distortion to noise-plus-distortion ratio
TCB	Telecommunication Certification Body (FCC recognized)
TDD	time division duplex
TDMA	time division multiple access
UMTS	Universal Mobile Telecommunications System
VBW	video bandwidth
W-CDMA	wideband code division multiple access

4. Measurement instrumentation

4.1 RF emission measurement instrumentation and peripheral equipment— General considerations

Use of proper measurement instrumentation is critical to obtaining accurate, reproducible test results. In this subclause is a list of equipment typically needed to determine the regulatory compliance of transmitters. Not all equipment listed below will be needed for every test. Specifications for each piece of equipment depend on the test to be performed. General specifications for each type of equipment are given in this clause. Various measuring accessories that may be needed depend on the particular measurements to be performed, as described in the following subclauses. Other instrumentation may be used, provided it has the necessary accuracy for the measurement to be performed. Various types of equipment which combine the capabilities of the devices listed below exist and may be used when the particular function meets the requirements for the specific measuring device type. Subclause 7.1 has additional requirements for instrumentation used for consumer signal booster network protection standard (NPS) test procedures.

- a) **Antennas:** See 4.4.
- b) **Audio generator:** To properly modulate voice radios, an audio generator will be needed that can generate audio tones in the range from 100 Hz to 20 kHz and which has sufficient dynamic range to provide the signal amplitude required to modulate a radio at 16 dB above the level required for 50% modulation deviation.
- c) **Base station simulator:** Many transmitters are used in network configurations that utilize base station with user equipment (and/or server/master with client) relationships where transmit parameters such as output power, modulation scheme, and occupied bandwidth (OBW) can be varied depending on existing transmit channel conditions. The simulator should provide accurate timing signals and be able to exercise Global Positioning System (GPS) circuits, as applicable. The channel conditions and appropriate transmit parameters are determined at the base station and instructions are communicated to the user devices. Because compliance requirements typically apply to the “worst-case” operational conditions, for testing purposes it becomes necessary to manually control these variable transmit parameters. Optimally, test software is provided with the device to be tested to permit manual control of the relevant transmit parameters, but when this is not an available option, a communications test set (also known as a call box) or base station simulator can be used to provide the necessary control over the variable transmit parameters. In many cases, these instruments also provide the capability to measure the cited RF parameters. The base station simulator should have the capability to exercise all modes and modulations for all transmit frequencies of the EUT.
- d) **Communications test set (also known as a call box):** Generates a modulated RF signal to simulate particular radio technologies, including suitable network and/or protocol control signals to remotely set the mode, band, channel, and/or power level of the equipment under test (EUT). It should provide accurate timing signals and be able to exercise GPS circuits, as applicable. For carrier-based network emulation, the output power of the communications test set is significantly lower than the output power of an actual network base station, because the propagation path length for testing purposes is much less than the actual propagation path length for normal operation. The test set shall have the same characteristic impedance as the antenna to be connected (for radiated coupling), or the EUT (for conducted coupling). The typical characteristic impedance is 50 Ω . The test set may include an integrated power meter, spectrum analyzer, audio analyzer or demodulator, modulation analyzer, or signal-plus-noise-distortion to noise-plus-distortion ratio (SINAD) meter, which can be used for compliance measurements if they meet the requirements for those measurement instruments. A communications test set may also include a base station simulator as well. The communications test set should have the capability to exercise all modes and modulations for all transmit frequencies of the EUT.
- e) **Directional coupler:** A directional coupler allows measurement of a high power signal indirectly through capacitive coupling. Directional couplers are necessary for conducted measurements of

high power transmitters, where attenuators are not available that can handle the output power levels of the transmitter under measurement. A directional coupler should be low loss on the path from the input to the output, but will generally have 40 dB or more of isolation of the input port from the forward power measurement port and the output port to the reverse power measurement port. The characteristic impedance of the directional coupler, generally 50 Ω , shall match the impedance of the cables, attenuators, terminators, and measurement instrumentation used. Directional couplers should be rated for a power in excess of the expected power level at the input port. A set of directional couplers may be necessary to accommodate the entire frequency range to be tested.

- f) **Dummy microphone:** To input audio frequency signals into some radios, a dummy microphone is required which can accept an input from an audio frequency generator. Audio input signals can be coupled directly to a transmitter via an audio input cable, or can be coupled from a speaker attached to the audio signal generator to the dummy microphone. The dummy microphone should be capable of passing audio signals across the full audio frequency range of 100 Hz to 20 kHz.
- g) **Environmental chamber:** An environmental chamber that controls temperature and humidity is needed for frequency stability testing. The chamber should be able to reduce temperatures to -40°C and raise temperatures to $+60^{\circ}\text{C}$. Humidity control is often required to reduce the effects of condensation and to prevent unwanted precipitation. The chamber shall have a temperature range to cover the test requirements.
- h) **Low noise preamplifier:** Used to improve the measurement system signal-to-noise level by increasing the signal amplitude prior to attenuation by cables attached to a spectrum analyzer or receiver. This reduces the overall system noise floor to a level that it is below the compliance limit, thus enabling a valid comparison of measured signals to the limit. A preamplifier is typically inserted in the signal measurement path to increase the amplitude of low signal levels present at the output of measurement antennas. Frequency response characteristics shall be suitable for the signals under measurement. Care must be taken to make sure that the preamplifier is not driven into saturation due to high input signal levels either at the fundamental or spurious frequencies. This can be prevented through the use of RF filters and/or suitable input attenuation. The preamplifier shall be impedance-matched with the remainder of the signal path (typically 50 Ω).
- i) **Measuring receiver:** Synonym for receiver; see 4.2.2.
- j) **Modulation analyzer:** A device used to measure the modulation depth or modulation deviation of a radio waveform. The instrument can also measure output power and distortion. This instrument is commonly embedded as a capability in other measurement instrumentation, such as communications test sets and base station simulators.
- k) **Network analyzer:** Used to characterize the gains, losses, and/or VSWR associated with passive networks, active devices, and signal propagation paths. Must have a frequency range suitable for the network, device, or system being characterized. Must have the same characteristic impedance (typically 50 Ω) as the network, device, or system being characterized.
- l) **Noise figure analyzer:** An instrument capable of measuring the noise figure of a device.
- m) **Oscilloscope:** Used with an RF detector to measure the temporal characteristics of an RF signal and to assess transient frequency behavior and other measurements. The bandwidth and sample rate of the oscilloscope must be adequate for the measurements being performed.
- n) **Power supply:** An adjustable ac or dc voltage (as appropriate for the power requirements of the EUT) is required for frequency and/or output power stability testing. The power supply shall have a range of at least $\pm 15\%$ relative to the nominal rated input voltage of the EUT.
- o) **RF cables:** RF cables should be as low-loss as possible and shall fully accommodate the frequency range of the measurement. Cables should maintain impedance-matching with respect to the measurement instrumentation used. RF cables shall provide adequate shielding from ambient signals that might influence the results. Cables should be bench calibrated prior to use in a test configuration with date of calibration recorded. See 4.5.4.

- p) **RF detector:** Used with an oscilloscope to measure the temporal characteristics of an RF signal. The RF detector shall have the same characteristic impedance at the RF port (typically 50 Ω) as the measuring antenna for radiated coupling) or the EUT (for conducted coupling). The combination of the detector and the oscilloscope must have a bandwidth greater than the bandwidth of the demodulated baseband signal. A matched low-impedance connection (i.e., 50 Ω) between the output of the detector and the input of the oscilloscope may be required to achieve the necessary video bandwidth (VBW). A matched impedance connection at the RF port of the detector may be required to achieve matched impedance at the video port of the detector.
- q) **RF filters:** Used to reduce the amplitude of fundamental signals when measuring radiated or conducted spurious emissions.²⁰ Inserted in the signal measurement path, typically directly after the measurement antenna and/or input attenuator, to prevent overload of low noise preamplifier and/or spectrum analyzer front end mixers. Frequency range and amplitude characteristics need to be suitable for the signals under measurement and must have the same characteristic impedance as the remainder of the signal path (typically 50 Ω).
- r) **RF power meter:** A peak measuring power meter and sensor, where permitted, may be used to measure the output power of the fundamental emission. The VBW of the peak power meter and sensor combination shall be greater than the OBW of the transmitter and the rise time of the detector shall be faster than the EUT pulse rise time or the rate of variation of the modulation envelope. For performing average power compliance measurements, an average power meter, or a peak power meter that averages multiple measurements, may be used where permitted, as long as it satisfies the requirements for VBW and rise time specified above. All types of power meters shall have an RF bandwidth that encompasses the fundamental emission frequency, and a dynamic range sufficient to accommodate the peak pulse power without clipping or non-linearity. Impedance is typically 50 Ω . Thermal power sensors can be used for measuring average power over broad frequency ranges and signal bandwidths. Typically thermal sensors are subject to thermal drift and must be compensated frequently. Diode sensors are more stable and can be calibrated over a broad frequency range. The development of wide bandwidth diode power sensors provides the most reliable and accurate instrument for the measurement of broadband complex modulated signals.
- s) **RF splitters/combiners:** Allows the splitting of an input signal in its working frequency range to multiple outputs or the combination of multiple signal inputs from different sources to a single output. A splitter/combiner shall maintain impedance matching with the rest of the test configuration and the EUT (conducted measurements) or the antennas (radiated measurements). Open circuit output (unused) ports shall be terminated with 50 Ω . Splitters/combiners should cover the frequency range of testing.
- t) **RF test receiver:** Synonym for receiver; see 4.2.2.
- u) **RF signal generator or vector signal generator:** A signal generator capable of generating continuous wave (CW) signals and applying specified modulation across the measurement frequency range. A CW signal is required to support the radiated substitution method of measurement. Signal generators can also be used to introduce intermodulation signals to the EUT and to simulate wireless protocols to send radio control signals in Global System for Mobile Communication (GSM) or Long-Term Evolution (LTE) formats to control a wireless handset. A signal generator shall be frequency and amplitude stable and shall maintain characteristic impedance matching with respect to the cables and equipment used in the test set-up (commonly 50 Ω).
- v) **Spectrum analyzer:** See 4.2.3.
- w) **Standard test load:** Dissipates the RF power from the antenna port of the transmitter under test. Used to suppress the radiated power level of the fundamental emission. Connected to the RF output port of the transmitter in place of an antenna that would be used in normal service. Must have the same characteristic impedance as the transmitter RF output port (typically 50 Ω) and be non-radiating. Must have a power rating greater than or equal to the output power of the transmitter, over the frequency range of the transmitter.

²⁰ Throughout this document, the terms “fundamental signal,” “fundamental emission,” and “fundamental power” denote signal, emission, and power, respectively, at the fundamental frequency, frequencies, or frequency band(s) of an EUT.

- x) **Vector signal generator:** Generates consistent digital baseband to simulate particular radio technologies. May be integrated within an RF signal generator or used to modulate a separate RF signal generator to yield a source signal for testing amplifiers or repeaters, or to generate signals for blocking tests using multiple tones or wideband modulations. Depending on the extent of the technology protocol and/or network control signals that can be generated, may be able to remotely set the mode, band, channel, and/or power level of a station radio EUT. A communications test set can be used for this same purpose, within the limitations of baseband formats and RF frequency range. The instrument shall have the same characteristic impedance (typically 50 Ω) as the antenna to be connected (for radiated coupling) or the EUT (for conducted coupling). When used as a base station simulator, the resultant signal shall represent the characteristics of the base band unit for which it is being substituted.

4.2 Spectrum analyzers and receivers

4.2.1 General

This standard recognizes that both spectrum analyzers and EMI receivers that conform to the specifications provided in ANSI C63.2 may be used for performing radiated or conducted emission and power measurements. A spectrum analyzer typically will not meet all requirements of an EMI receiver stated in ANSI C63.2 without additional accessories. Appropriate accessories, such as a pre-selector, a quasi-peak detector,²¹ and specific IF filters may be used with a spectrum analyzer to make it equivalent to an EMI receiver, thus satisfying the requirements of this standard.

4.2.2 Receiver

The minimum specifications of an EMI receiver for performing measurements of radiated emissions and antenna port conducted RF power are provided in ANSI C63.2. All measurements shall be made using a resolution bandwidth (RBW) defined at the -3 dB points, except when quasi-peak measurements, are specified, in which case the RBW is defined by the -6 dB points. Many modern receivers allow selection of either 6 dB or 3 dB RBW filters, so care should be taken to make sure that the correct settings are used. Scanning receivers may be used, but the scan rate shall be selected such that a calibrated instrument response is validated and emissions are properly detected (e.g., only during active full-power transmission) and the amplitude of each emission is measured correctly. Bandwidths shall be chosen that are appropriate for the frequencies being investigated and the regulatory requirements being evaluated. Receivers often include a spectrum analyzer capability which can be used if it meets the requirements for a spectrum analyzer specified in 4.2.3.

4.2.3 Spectrum analyzer

Spectrum analyzers are the primary instruments used for performing fundamental-band emission power, OBW, and unwanted emissions measurements. Additional external accessories can be required, such as RF filters and preamplifiers, as discussed below.

Reference bandwidth specifications are typically provided in the applicable regulatory requirements. These specifications may be expressed in absolute values or as a percentage of the signal's OBW or nominal channel bandwidth. The RBW specification is considered to be relative to 3 dB bandwidth of the IF (resolution) filter. It should be noted that most spectrum analyzers incorporate a 3 dB RBW specification, but use may require a physical selection.

²¹ Quasi-peak is used only for specific types of transmitters operating in the licensed radio services.

Narrower RBWs may be used where allowed by this standard or when specified by the regulatory requirements. Generally, the measurement must be corrected to account for the narrower bandwidth by integration across the specified reference bandwidth, or by adding $10 \log [(reference\ bandwidth) / (resolution\ or\ measurement\ bandwidth)]$ to the measured value (such bandwidth scaling is limited to cases where the measurement bandwidth used to perform the measurement is less than the reference bandwidth). The bandwidth correction factor discussed above applies only to noise-like broadband signals with relatively flat spectral characteristics within the passband of the resolution filter. Power integration using the measurement instrument is the preferred method as it typically yields more accurate results. Where the OBW of the signal under measurement is less than the RBW of the measuring instrument, no bandwidth correction or integration will be required.

For a spectrum analyzer to meet the EMI receiver specifications of ANSI C63.2, it often must be augmented with proper filtering (preselection) and external RF attenuation at the input, which will provide adequate overload protection and dynamic range of the system to achieve the proper weighting of pulses. With these augmentations, a spectrum analyzer can be made to perform as a scanning EMI receiver, while satisfying the specifications for the RBW and pulse weighting.

When using spectrum analyzers, the following issues must be considered:

- a) *Overload*—Many spectrum analyzers have no RF pre-selection above a specified frequency range; i.e., the input signal is fed directly into a broadband mixer. To avoid front-end overload, prevent potential instrumentation damage, and to ensure operation within the linear boundaries of a spectrum analyzer, the maximum signal amplitude introduced at the mixer shall be limited to the manufacturer's specified mixer input specification. External (relative to the measurement instrument) RF attenuation or pre-selection may be required in some cases to realize this requirement.
- b) To assist in ensuring that the input mixer of the measurement instrument operates within its linear region, the internal input attenuator should be set to auto-couple. In this mode, the input attenuation is coupled to the reference level and the instrument automatically selects the optimal setting. If finer control of the input attenuation is required to achieve a sufficiently low noise floor (e.g., when performing out-of-band emissions measurements), then the attenuation can be set manually, provided that the power level of the input signal at the input of the mixer is maintained below the maximum level specified by the instrument manufacturer. The signal level at the input mixer can be determined from: (Reference Level – Input Attenuation). When measuring the power of narrowband signals, the maximum signal amplitude must be displayed at or below the spectrum analyzer reference level.
- c) When measuring the amplitude of broadband signals, to prevent mixer overload the maximum power measured within the RBW [i.e., the power spectral density (PSD)] must be maintained below the reference level by an amount determined from the following approximation (emission bandwidth (EBW) can be used in lieu of OBW, if necessary):
$$\text{Displayed Level} \leq \text{Reference Level} - 10 \log (\text{OBW/RBW})$$
- d) When utilizing average measurement techniques in accordance to the procedures provided herein, the peak-to-average power ratio (PAPR) associated with contemporary modulation/multiple access schemes must also be considered. In these cases, the proper reference level and input attenuation can be set initially by using the peak detector followed by a final measurement performed with the specified average detector, while maintaining the same reference level and/or input attenuation settings.
- e) Additional amplitude separation between the maximum input signal level and the spectrum analyzer reference level may be required if the signal under measurement is pulsed and its output power or PSD are to be averaged over the duty cycle. In this case, an additional amplitude margin relative to the reference level, determined from $10 \log(1/\text{duty cycle})$, may be required. For example, the reference level should be set 3 dB higher if the settings are based on power or PSD measurements that are averaged over a 50% duty cycle. This correction must be made in addition to

the PAPR correction described above. When performing fundamental emission power measurements, the reference level setting shall be based on the maximum fundamental power at the input to the spectrum analyzer. As a measurement precaution, any signals input to the measurement instrumentation should be suspected of having the potential for overload until proven otherwise.

- f) The reference level established in performing the fundamental emission output power measurement shall be maintained when performing unwanted emissions measurements to ensure that the instrument is not being overloaded by the fundamental power, unless filtering at the instrument input (preselection) is employed to reduce the contribution of the fundamental power at the mixer. Some instruments (e.g., EMI receivers) utilize an “auto-ranging” function to optimize the input attenuation at each tuned frequency to prevent overload of the input mixer and optimize the available dynamic range. Measurement instruments that implement a stepped frequency measurement technique (i.e., measurements performed at discrete step frequencies) may enable automatic attenuation setting at each tuned frequency as a means for avoiding overload conditions. Swept EMI receivers that continuously tune the instrument over the frequency range of interest (instead of tuning to individual frequencies) may also utilize automatic attenuation detection and setting at the end of a sweep, based on measured amplitudes collected over the sweep. Multiple sweeps may be required if amplitude values are detected in the sweep that indicates potentially excessive power levels. In both cases, this auto-ranging feature can be used to automatically determine a proper reference level and input attenuation setting at the cost of increased measurement time. Ultimately, the test personnel are responsible for ensuring linear operation of the measurement instrument.
- g) *Linearity test*—Linearity can be verified by a simple test that involves measuring the amplitude level of the signal under investigation and then repeating the measurement with a known amount of RF attenuation inserted at the input of the measuring instrument (or external preamplifier, if used). A comparison of the measured amplitudes should be within ± 0.5 dB relative to the applied attenuation, to ensure measurement system linearity for a specific input power. In the case of broadband time-variant signals and spread-spectrum signals, the linearity test described above may be performed by selecting the peak power detector in combination with the maximum hold function. The amount of attenuation should be selected in consideration of the potential for raising the measurement system noise floor; in particular it should not be selected so large that it will raise the noise floor to within 6 dB of the signal level under measurement.
- h) *Normal response to pulses*—The response of a spectrum analyzer using quasi-peak detection shall be verified with the reference test pulses specified in CISPR 16-1-1:2010 [B6]. The large peak voltage of the reference test pulses (defined in CISPR 16-1-1) typically requires the use of RF attenuation of 40 dB or more to satisfy the linearity requirements. This decreases the sensitivity and makes the measurement of low repetition rate and isolated calibration test pulses difficult for CISPR bands B, C, and D.²² If a pre-selection filter is used in front of the spectrum analyzer, the RF attenuation can be decreased. The filter limits the spectral density of the calibration test pulse as seen by the mixer.
- i) *Signal interception*—The spectrum of time varying emissions may be captured with peak-detection and digital display storage (“maximum hold” function). Multiple, fast frequency scans reduce the time to intercept an emission compared to a single, slow frequency scan. The starting time of the scans shall be varied to avoid any potential synchronization with the emission, thereby masking it. The total observation time for a given frequency range shall be long enough to capture any emissions present. Depending upon the type of disturbance being measured, peak detection measurements can be used to replace all or part of any compliance measurements where quasi-peak or average detection is specified (under the presumption that peak-detected measurements will always provide “worst-case” results).
- j) *Average detection*—Shall be made with a spectrum analyzer equipped with a linear average detector as specified in 4.3.1.

²² CISPR 16-1-1:2010 [B6] band B is 0.15 MHz to 30 MHz, and bands C and D are 30 MHz to 1000 MHz.

- k) *Selection of display mode*—The display mode shall be set appropriate to the display detector(s) being used to perform the measurement (e.g., “Positive Peak” or “Power Average (rms)” detection mode). It may be necessary to select the correct display mode to determine that average measurements are performed in a linear mode.
- l) *Bin size*—When using sample or average detectors, the spectrum analyzer’s bin size shall be no larger than one-half of the measurement (resolution) bandwidth (RBW/2).

4.3 Detector functions and selection of bandwidth

4.3.1 General considerations

Unless otherwise specified, EMI receivers and spectrum analyzers shall have the detector functions and bandwidths specified in ANSI C63.2. Peak detection measurements can be used to replace all or part of any compliance measurements where quasi-peak or average detection is specified (under the presumption that peak-detected measurements will always provide “worst-case” results). The bandwidths used shall be equal to or greater than those specified in ANSI C63.2. Use of bandwidths greater than those specified may produce higher readings for certain types of emissions and thus shall be noted in the test report. More than one instrument may be required to examine the complete frequency range of interest. The IF filter bandwidths (RBW) are specified at the –3 dB points. The use of IF filters (RBW) defined at the –6 dB points is acceptable only for quasi-peak measurements, when required. The measuring instrument shall satisfy the following provisions:

- The average detector shall have a linear response and shall meet the linear average specifications in ANSI C63.2. The average detector used shall be in accordance with the applicable regulatory requirements. Depending on the specific regulatory requirements, a voltage average detector, or a power average detector (rms) may be used. Compliance data produced with log-average detector when performing average measurement are not acceptable. When measuring a periodic emission, the dynamic range of the measuring instrument shall be adequate to provide correct results.
- When using a spectrum analyzer (or other measurement instrument that implements a VBW function) for performing peak measurements, the VBW shall be set to a value that is at least three times greater than the IF (resolution) bandwidth (RBW) of the measuring instrument to avoid the introduction of smoothing or averaging effects.

4.3.2 Specific detector modes and bandwidths for transmitter compliance measurements

Measurements of conducted and radiated emissions from transmitters utilize a wide range of detector modes and measurement bandwidths that will vary depending upon the regulatory requirements being applied. The following discusses the most common detector modes required to perform compliance measurements on the licensed transmitters considered within the scope of this standard.

4.3.2.1 Measurement bins and trace display points

Modern signal/spectrum analyzers utilize digital displays with a finite number of trace display points. Often, signal/spectrum analyzers sample at a number of frequencies that exceed the number of trace display points. Therefore the amplitude value that is shown at a certain display point is determined from the data accumulated within what is known as a measurement bin or bucket. The width of the measurement bin is determined by the number of trace points and the frequency span in the frequency domain or the sweep time when operating in the time domain. Each bin contains data from a frequency span and/or timeframe that is determined by the following equations:

- a) Frequency domain: $\{\text{bin width} = [\text{span}/(\text{trace points} - 1)]\}$
- b) Time domain (zero span): $\{\text{bin width} = [\text{sweep time}/(\text{trace points} - 1)]\}$

The methodology used to determine the displayed amplitude from the multiple data points in each bin is determined by detector selection.

4.3.2.2 Peak (positive) detection mode

The simplest way to measure all RF signal components at their highest amplitude is to store and display the maximum amplitude level detected within each measurement bin. This is the positive peak or peak detection mode. Peak detection is typically the default mode offered on most spectrum analyzers because it is necessary that all RF signal components are detected independent of the ratio between RBW and bin width. Peak detection will not always provide an accurate amplitude representation of random or pseudo-random noise-like signals.

4.3.2.3 Pulse desensitization

Some transmitters generate wideband emissions using extremely narrow pulses. Compliance measurements are typically performed with a receiver or spectrum analyzer. Depending on various factors (RBW, pulse width, etc.), the spectrum analyzer may not display the true peak value of the measured emission. This effect, called “pulse desensitization,” relates to the capabilities of the measuring instrument and the characteristics of the emission. For the measurement and reporting of the true peak of pulsed emissions, it may be necessary to apply a pulse desensitization correction factor (PDCF) to the measured value. In other words, the test report must include the corrected peak level of the emission when the limit is specified in terms of a peak emission, which may necessitate the use of a PDCF.

NOTE—A PDCF typically applies only to peak emission measurements. As an example, where a requirement specifies that a minimum 1 MHz RBW is required for emission measurements above 1000 MHz, when pulse widths are narrower than the inverse of the RBW employed by a spectrum analyzer, the PDCF is applied to the peak level measured on the spectrum analyzer to compensate for the inability of the analyzer to respond fast enough to reflect the true peak power, i.e., the spectrum analyzer does not have sufficient bandwidth to measure all of the energy in the pulsed signal.

4.3.2.4 Quasi-peak detection mode

The use of a quasi-peak detector (QPD) is sometimes specified for measuring signal amplitudes at frequencies below 1 GHz. The QPD output is a weighted form of peak detection. The measured value of the QPD is reduced as the repetition rate of the measured signal decreases. The signal weighting is accomplished by circuitry with specific charge, discharge, and display time constants that are defined in CISPR 16-1-4 [B7]. Most regulatory authorities will accept peak-detector measured data in cases where QPD measurements are specified.

4.3.2.5 Average detector modes

4.3.2.5.1 General

Many modern digital modulation schemes exhibit noise-like power characteristics that are more accurately measured by displaying the average value of the samples accumulated within each bin. In addition, because of instrumentation limitations on the available RBW relative to the signal OBW associated with contemporary broadband modulation/multiplexing schemes, integration (summing) of the power must often be performed across a range of frequency bins. Several detection techniques can be used to average the data samples within each bin to determine the appropriate display value. When utilizing an average detector, the bin width shall be less than or equal to 50% of the RBW.

The most common average detector methodologies are power averaging (rms), voltage averaging, and log-power (video) averaging. Log-power averaging is not permitted for demonstrating compliance by most regulatory authorities, and therefore is not included in this standard.

4.3.2.5.2 Power averaging (rms)

The averaging detector is often referred to as an “rms” detector when it averages power (based on the root mean square of measured voltage) because the displayed values are determined by taking the square root of the sum of the squares of the voltage data measured during the bin interval divided by the characteristic input impedance of the spectrum analyzer (normally 50 Ω). Power averaging determines the average power of measured signal and is the best choice for measuring the power of complex modulated (noise-like) signals.

4.3.2.5.3 Voltage averaging

The voltage averaging detector averages the linear voltage data of the envelope signal measured during each bin interval. It is often used for measuring emission amplitudes of narrowband signals. Voltage averaging is also useful for observing rise and fall behavior of amplitude-modulated or pulse-modulated signals, such as with radar and time division multiple access (TDMA) transmitters.

4.4 Antennas

4.4.1 General

When performing radiated emission testing, the choice of specific types of measurement and/or substitution antenna will depend on the frequency range under measurement. Table 1 provides a summary of typical antenna types used in performing compliance measurements for transmitters. The antennas in this list are acceptable for use in the specified frequency ranges, whether used as a measurement antenna or as a substitution transmit antenna during radiated emissions testing.

4.4.2 Measurement antennas

When radiated emissions tests are performed (e.g., spurious radiation tests or compliance tests performed on an EUT with no accessible antenna port or with a properly terminated antenna port), one or more antennas appropriate to the frequency range under measurement must be selected from Table 1 as the receiving (measurement) antenna. When performing radiated measurements, the measurement distances should be chosen to be greater than or equal to the far field distance whenever possible.

4.4.3 Substitution antennas

Radiated compliance testing of transmitters may require the use of substitution methods. The substitution method involves the use of a measurement antenna, which will be used to receive the signals emanating from both the EUT and from a transmit antenna “substituted” for the EUT. The substitution antenna is used to transmit a generated signal to the measurement antenna, to duplicate the emission amplitudes that were previously observed to be emanating from the EUT. The antenna used to transmit the substitute signal should be a half-wave dipole with average VSWR of less than 1.5:1 and no more than 1 dB insertion loss. However, in some cases, the use of a half-wave dipole with these characteristics can be unrealizable, particular at higher frequencies (very short wave-lengths). As such, any antenna in Table 1 can be used as a transmit antenna in substitution measurements, provided that the rated gain is expressed as relative to either equivalent dipole or equivalent isotropic antenna gain (e.g., dBd or dBi). The substitution antenna shall have a traceable calibration. Antennas for use above 30 MHz shall be linearly polarized.

Below 30 MHz, substitution method testing is not required. Rather, the magnetic field strength is measured using a loop antenna and the result is converted to EIRP, ERP, or radiated field strength as specified by the applicable requirements. By convention, magnetic field strength is converted to an electric field strength based on the free space impedance [$1 \mu\text{V/m} = (377 \Omega) \times 1 \mu\text{A/m}$], then electric field strength is converted to radiated power using the equation in item d) of 5.2.7.

Table 1—Antennas (and their frequency ranges of operation) for use in making measurements on transmitters

#	Antenna types ^a	9 kHz to 150 kHz	0.15 MHz to 30 MHz	30 MHz to 1000 MHz	Above 1 GHz
1	Loop (passive)	Yes	Yes	No	No
2	Loop (active) ^b	Yes	Yes	No	No
3	Resonant tuned dipole (passive)	No	No	Yes	No
4	Biconical dipole (50 Ω or 200 Ω balun) ^c	No	No	Yes	No
5	Precision biconical dipole	No	No	No	Yes
6	Log-periodic dipole array (LPDA)	No	No	Yes	Yes ^d
7	Hybrid (bicon/log)	No	No	See footnote e	See footnote e
8	Waveguide horn	No	No	No	Yes
9	Double-ridged guide horn	No	No	No	Yes ^f

^a To be acceptable for use in making final compliance measurements, each antenna used as a reference or measurement antenna shall have a current, valid calibration that has been performed in accordance with ANSI C63.5, and, which is evidenced by means of a calibration certificate/report that among other things states the specific antenna calibration method or methods used, the antenna factors determined for that specific antenna, and the associated calibration measurement uncertainty. Gain can be calculated from the calibrated antenna factor AF using: $G = 20 \log(F) - AF - 29.8$ (for a 50 Ω system), where G is the antenna gain in dB, AF is the antenna factor in dB/m, and F is the measurement frequency in MHz. For further details in regard to antenna calibration, see 4.5.3.

^b When loop antennas are used for making exploratory or relative-comparison measurements, the use of an active loop antenna is permitted when these measurements are made in a shielded enclosure (e.g., an RF anechoic chamber). The use of an active loop antenna is permitted when making exploratory or relative-comparison measurements in a non-shielded environment (e.g., an OATS) if the active loop antenna is equipped with an operating saturation indicator and only if the saturation indicator is monitored during the course of the testing and that the monitor does not indicate saturation.

^c The use of precision broadband omnidirectional (biconical) antennas complying with the constructional and pattern requirements specified in 8.3.3.1 of CISPR 16-1-4:2010 [B7] are permitted when making final compliance measurements on transmitters. No other types of biconical antennas shall be used above 1 GHz for making final compliance measurements.

^d Users of LPDA antennas are cautioned that the required calibration methods for these antennas at frequencies up to and including 1 GHz are different from those required to be used at frequencies above 1 GHz. Users are further cautioned that for the case of an LPDA antenna whose operating frequency range extends above 1 GHz, that antenna shall be acceptable for use in making final compliance measurements on transmitters only if the calibration certificate or report for that antenna explicitly states the differences between the calibration methods used up to 1 GHz relative to the calibration method used above 1 GHz and lists the antenna factors applicable at 1 GHz and below separately from those applicable above 1 GHz.

^e There are potential issues with the use of hybrid antennas in specific measurement environments. For further guidance on the use of hybrid antennas, see ANSI C63.4:2014. Note that a hybrid antenna is not acceptable as an alternative to a half-wave dipole substitution antenna.

^f The aperture dimensions of horn antennas shall be small enough so that the measurement distance in meters is equal to or greater than the Rayleigh (far-field) distance (i.e., $R_m = 2D^2 / \lambda$), where D is the largest dimension of the antenna aperture in meters and λ is the free-space wavelength in meters at the frequency of measurement. Such antennas include double-ridged waveguide horns, rectangular waveguide horns, pyramidal horns, optimum gain horns, octave-bandwidth horns, and standard gain horns. The main lobe of the radiation pattern for any antenna used shall be large enough to encompass the physical size of the EUT, or system arrangement, when located at the measuring distance. See 5.5.2.3 for details about techniques for encompassing products with the measurement antenna radiation pattern during the measurement process where this condition is not fulfilled. In case of dispute, measurements made with a standard-gain horn antenna shall take precedence. Horn antennas with active components such as built-in amplifiers can be used as a measurement antenna, but should not be used as substitution (transmit) antennas.

4.5 Calibration of measuring equipment

4.5.1 General calibration equipment requirements

All instruments that can have a significant effect on the accuracy or validity of measurements performed as specified in this standard shall be calibrated in accordance with the manufacturer's calibration procedure and the instrument requirements of ANSI C63.4 and ANSI C63.5. A calibration system shall be maintained, as part of a laboratory quality system, which monitors the calibration status of the test equipment and provides for the traceability to national standards.

4.5.2 Confirmation interval

The calibration of all instruments shall be confirmed in the first year of deployment. The subsequent recalibration intervals may be longer [up to three (3) years] or shorter based on review of calibration data relative to the recommendations of the instrument manufacturer and the required measurement accuracy. All instruments shall be checked as frequently as necessary between calibration intervals to provide evidence that instrument accuracy and system measurement uncertainty is continuously maintained (see ISO 10012:2003 [B43]).

4.5.3 Antenna calibration

All antennas shall be calibrated per ANSI C63.5. Antennas shall be recalibrated at regular intervals (i.e., periodically recalibrated) as described in 4.5.2, and recalibrated after repair when damage or deterioration is suspected or known to have occurred. Notwithstanding the provisions of the preceding sentence:

- a) Standard gain horns need not be periodically calibrated, unless damage or deterioration is suspected or known to have occurred. The connector shall be checked periodically for damage. If a standard gain horn is not periodically calibrated, its critical dimensions (see Annex A of IEEE Std 1309™-2013 [B40]) shall be verified and documented on an annual basis.
- b) Precision broadband omnidirectional (biconical) antennas complying with the constructional and pattern requirements specified in 8.3.3.1 of CISPR 16-1-4:2010 [B7] need not be periodically recalibrated, unless damage or deterioration is suspected or known to have occurred. The connector shall be checked periodically for damage.

4.5.4 Cable, attenuator, filter, and directional coupler insertion loss

The insertion losses associated with connecting cables and other interface devices such as filters, attenuators, and directional couplers shall be characterized, and checked frequently (monthly or before each use) for deterioration caused by use and environmental exposure (e.g., variation due to change in temperature, or physical damage). Signal attenuation in coaxial cables can vary with temperature variations. Consequently, the temperature at the time of the initial cable loss characterization and at the time of the product testing shall be recorded. When the temperature differential between calibration and actual usage is known to be ≥ 15 °C, the cable characterization shall be repeated.

4.6 Test sites

4.6.1 General

Specifications are provided below for two categories of radiated test sites. The first category describes the minimum requirements for test sites to be used in performing substitution measurements (although, this radiated test methodology can utilize either category). The second category of test sites defines the minimum requirements that must be realized to perform direct radiated field strength measurements based on a pre-characterized path loss (i.e., not utilizing the traditional two-stage substitution measurement for every emission). A test site that conforms to the requirements specified ANSI C63.4, and that has been validated as such, shall be utilized for performing direct field measurements and may be used for performing substitution measurements.²³

²³ Some regulatory authorities require a test site meeting the requirements of ANSI C63.4 for performing the substitution method for radiated emission testing.

4.6.2 Test site requirements for performing radiated emissions measurements using the substitution measurement method

4.6.2.1 Standard radiation test site (3 m test distance)

The test site shall be on a level surface that is of uniform electrical characteristics. The site shall be clear of metal objects, overhead wires, etc., and shall be as free as possible from undesired ambient RF noise, including ignition noise, high-power broadcast signals, and other sources of undesired RF noise. The distance from the EUT or the measurement antenna relative to any potential RF reflecting objects shall be greater than 3 m. The EUT shall be placed on a remote-controlled turntable that is installed flush with the ground plane. A non-conducting platform 80 cm above the ground plane shall be provided on this turntable to support the EUT. A conductive ground plane consisting of no greater than 1.3 cm square soldered mesh wire shall extend to or beyond the two 3 m radius circles described above. If desired, RF-transparent radome shelters may be provided for the equipment and personnel at both ends of the test site. All such construction shall be of wood, plastic, or non RF-reflective material. All power, telephone, or control circuits to the site shall be placed below the conductive ground plane.

4.6.2.2 Standard radiation test site (30 m test distance)

The test site shall be on level ground that is of uniform electrical characteristics. The site shall be clear of metal objects, overhead wires, etc., and shall be as free as possible from undesired signals such as ignition noise, other carriers, etc. The distance from the unit under test or the test antenna to reflecting objects such as rain gutters, house plumbing, etc., shall not be less than 90 m. At the transmitter or receiver end, a turntable essentially flush with the ground, should be provided that can be remotely controlled. A non-conducting platform 80 cm high shall be provided on this turntable to hold the EUT. If desired, radome shelters may be provided for the equipment and personnel at both ends of the test site. All such construction shall be of wood, plastic, or other nonmetallic material. All power, telephone, or control circuits to the site shall be buried at least 0.3 m deep.

4.6.2.3 RF anechoic chamber

An RF anechoic chamber is one in which all interior surfaces are covered by electromagnetic absorption material that suppresses reflections to simulate free space propagation path conditions. Both the EUT and the measurement antenna are located within the chamber interior. The chamber shall be sufficiently large to allow far-field separation distances at the lowest frequency of measurement. The chamber may also provide additional attenuation to potentially disruptive ambient RF noise.

4.6.3 Test site requirements for radiated emission measurements using the direct radiated field strength method based on a pre-characterized path loss

4.6.3.1 Test sites for below 30 MHz

The test site for performing radiated emission testing at frequencies below 30 MHz shall be relatively free from metal objects, buried pipes, and any objects that may affect radiated measurements. The alternative site shall also be capable of meeting the test site requirements of ANSI C63.4 as specified for below 30 MHz. An alternative test site that can demonstrate equivalence to a test site as described above shall be acceptable.

4.6.3.2 Test sites for 30 MHz to 1000 MHz

Radiated field strength or power measurements for frequencies from 30 MHz and up to and including 1 GHz shall be made at a test site that satisfies the requirements defined in ANSI C63.4 (see 4.4 therein). Test site validation criteria shall demonstrate that the site meets the normalized site attenuation requirements specified in ANSI C63.4 for below 1 GHz.

4.6.3.3 Test sites for 1 GHz to 40 GHz and above

For measurements of RF emissions at frequencies from 1 GHz to 40 GHz, the test site shall conform to the site validation criterion specified in ANSI C63.4. For measurements above 40 GHz, reflection contributions shall be reduced to the extent possible in consideration of practical limitations.

4.6.4 In situ testing

In some circumstances (e.g., large base station transmitters) compliance measurements may be required to be performed with the EUT operated in situ (i.e., situated in the original, natural, or existing place or position). In such cases, the specific EUT test set-up used must be coordinated and approved by the relevant regulatory agency prior to use.

5. Basic measurement considerations for transmitters

The following general measurement procedures shall be used for determining compliance of transmitters, unless another procedure is deemed to take precedence. See Clause 6 for exceptions applicable to specific transmitters.

5.1 Frequency range and number of fundamental frequencies to be tested

5.1.1 Frequency spectrum to be investigated²⁴

- a) When required for measurements of conducted and radiated emissions, the spectrum shall be investigated from the lowest RF signal generated in the equipment, without going below 9 kHz, up to at least the frequency shown below.
 - 1) If the equipment transmits below 10 GHz, unwanted emissions measurements shall be performed up to the tenth harmonic of the highest fundamental frequency or to 40 GHz, whichever is lower.
 - 2) If the equipment transmits at or above 10 GHz and below 30 GHz, unwanted emissions measurements shall be performed up to the fifth harmonic of the highest fundamental frequency or to 100 GHz, whichever is lower.
 - 3) If the equipment transmits at or above 30 GHz, the measurements shall be performed up to the fifth harmonic of the highest fundamental frequency or to 200 GHz, whichever is lower.
- b) Particular attention should be paid to harmonics and sub-harmonics of the carrier frequency, as well as to those frequencies removed from the carrier by multiples of the oscillator frequency. Radiation at the frequencies of multiplier stages should also be checked.
- c) The amplitude of spurious emissions which are attenuated more than 20 dB below the permissible value need not be reported.

5.1.2 Number of fundamental frequencies to be tested in EUT transmit band

5.1.2.1 General requirement

Measurements of transmitters shall be performed and, if required, reported for each frequency band in which the EUT can be operated with the device transmitting at the number of frequencies in each band specified in Table 2.

²⁴ See 47 CFR 2.1057.

Table 2—Number of frequencies to be tested

Frequency range over which EUT operates	Number of frequencies	Location in frequency range of operation
1 MHz or less	1	Middle
1 MHz to 10 MHz	2	1 near top and 1 near bottom
More than 10 MHz	3	1 near top, 1 near middle, and 1 near bottom

5.1.2.2 Test channels and test modes (streamlined test requirements)²⁵

Measurement of all modes and all channels is not always necessary to demonstrate compliance. Regardless of the test reduction methods selected, a device must comply with all the applicable rule parts under all modes of operation. A detailed technical rationale must be provided as justification for the selection of a subset of operational modes as being representative of “worst case” conditions.

5.2 RF output power measurement procedures

This subclause provides guidance for performing the power measurements necessary to demonstrate compliance to the RF output power limits imposed by regulatory authorities on transmitters. In addition, these procedures can also be utilized to collect the data necessary to demonstrate compliance to regulatory limits placed on unwanted (out-of-band and spurious) emissions.

5.2.1 RF power measurement instrumentation considerations

There are several choices available with respect to instrumentation that can be used to perform the measurement of EUT output power, whether it be the output power associated with the fundamental emission or the power contained within unwanted (out-of-band and/or spurious) emissions. Typical instruments used to perform power measurements include RF power meters, spectrum analyzers, EMI receivers, and vector signal analyzers. Clause 4 provides detailed information regarding these instrumentation choices and the capabilities that are necessary for performing these measurements.

A power meter is widely recognized as the most accurate instrument for performing absolute power measurements; however, due to a lack of RF selectivity, limited modulation (video) bandwidth, and limited display capabilities, they typically do not offer much flexibility for use in performing more than just power measurements of the fundamental emission (i.e., they typically don’t offer the capabilities necessary for measuring other compliance parameters such as OBW and PSD).

Most digital spectrum/signal analyzers and EMI receivers are equipped with a power averaging (rms) display detector that can provide near power meter accuracy while also offering the flexibility for use in collecting the data necessary to demonstrate compliance to most of the other regulatory requirements. Thus, spectrum analyzers, signal analyzers, and EMI receivers (with spectrum analyzer mode) have become the primary instruments of choice when performing compliance measurements, including RF output power measurements. Most contemporary versions of these instruments utilize digital displays and the display detector modes discussed in 4.2 are commonly implemented across these various platforms. Because older analog spectrum analyzers and EMI receivers typically do not offer the requisite display detectors specified in this standard, they are typically not suitable for use in performing average output power final measurements of noise-like signals.

Finally, it should be noted that many contemporary transmitters operate in network topologies in which client device transmission characteristics are controlled by a master server or base station. When measuring the maximum RF output power from such devices, control over the EUT must be provided either through special test software (provided by manufacturer specifically for compliance testing, but not accessible by an

²⁵ Use of the procedures in 5.1.2.2 is subject to the discretion of the regulatory authority.

end user) or through use of a base station emulator, communications test set, call box, or similar instrumentation that is capable of establishing a communications link with the EUT to enable control over variable parameters (e.g., output power, OBW, etc.). In some cases, these instruments also include basic digital spectrum analyzer and/or power meter capabilities that can be utilized to measure the RF output power if the specified detectors and requirements can be realized and the measurement functions have been calibrated.

5.2.2 RF signal type considerations

From a compliance measurement perspective, RF signals can be classified into one of three general categories, based on certain shared attributes. CW-like RF signals are similar to a true CW signal in that they exhibit a constant amplitude and frequency, demonstrate a PAPR of near zero decibels, and tend to be narrowband. Noise-like signals share similarities with additive white gaussian noise (AWGN) in that the average RF power is proportional to the measurement bandwidth, the peak power is a random variable, and the PAPR tends to be high. Pulse-like signals (including burst communications) share periodicity attributes with true pulse signals (e.g., pulse width, pulse repetition frequency, duty cycle) and are often associated with time division duplex (TDD) or TDMA technologies.

When setting up an RF output power measurement, decisions regarding the appropriate measurement instrumentation and procedures to use should take into consideration the type of RF signal involved. For example, because the PAPR of a CW-like signal is approximately zero dB, there is typically little benefit to be realized from performing average RF output power measurements. Thus, it is often preferable to use a peak power measurement procedure because of the relative simplicity. However, if the signal under measurement is noise-like, then the RF output power is best characterized by an average power measurement (rms) since the peak power is a random variable that can only be precisely expressed on a statistical basis. Because of the regulatory requirement to measure RF output and unwanted emissions power levels only during active, full-power transmissions (i.e., no allowance for duty cycle or duty factor corrections), the appropriate instrumentation and procedures for measuring the power associated with pulse-like signals should be selected based on the underlying (non-pulsed) signal type (i.e., CW-like or noise-like).

In addition to the RF signal type to be measured, the OBW of the signal must also be considered. Within this standard, two categories of signals are defined based on their OBW relative to the measurement bandwidth or RBW of the measuring instrument. A signal is considered to be narrowband if its OBW can be fully encompassed within the measurement bandwidth or RBW of the instrument. A broadband signal is one in which the OBW cannot be fully contained within the instrument's measurement bandwidth or RBW, necessitating the use of integration techniques. When utilizing integration methods to measure the power in a broadband signal, special consideration must also be given to protecting the instrumentation from overload thus degrading the integrity of the measured data (see 4.2.3).

The procedures below provide guidance for measuring the RF output and unwanted emissions power for any of the signal types (e.g., CW-like, noise-like, or pulse-like) and OBW combinations (narrowband or broadband) discussed above. Measurement procedures are provided for measuring total peak output power, total average output power, peak and average PSD, and PAPR, for narrowband and broadband CW-like, noise-like, and pulse-like signals. These procedures are intended for use when performing conducted power measurements, but can also be used for performing radiated power measurements within the constraints specified elsewhere in the standard (e.g., see 4.6 and 5.5).

5.2.3 Peak power and power spectral density measurements

5.2.3.1 General

Some regulatory requirements specify the RF output power limits in terms of total peak output power or peak power spectral density (PPSD), often expressed as either peak conducted power, peak effective

radiated power (ERP), or peak equivalent isotropically radiated power (EIRP). See 5.2.5.5 for guidance on determining ERP and EIRP from measured output power data.

Total peak power is often implied when the limits are stated as peak power, ERP, or EIRP with no further specification with respect to a reference bandwidth. When a reference bandwidth is specified in conjunction with peak power, ERP, or EIRP limits, then the PPSD is measured to demonstrate compliance to the relevant limits.

Even when the RF output power or unwanted emissions limits are expressed in terms of average power or PSD, including ERP or EIRP, it is usually acceptable to demonstrate compliance with peak power measurement data under the presumption that the peak power level will always be greater than or equal to the average power level, regardless of RF signal type.

The peak power in a narrowband noise-like signal can be measured using the same techniques as used for a CW-like signal, wherein the instrument's measurement bandwidth or RBW and VBW can accommodate the entire signal OBW, and an adequate dwell time is employed. However, because the total peak power of a noise-like signal is a random variable, measurements utilizing swept-frequency detection may not capture the true peak level on an accurate and repeatable basis. For this reason, total peak power is not typically specified as an output power limit for broadband noise-like signals. However, if a need should arise to measure the total peak power of a broadband noise-like signal, then either a wideband peak power meter with a fast-responding diode detector and a VBW greater than or equal to the OBW, or the complimentary cumulative distribution function (CCDF), available on most modern RF power measurement instrumentation, offer the best options.

The following procedures provide guidance for measuring the total peak power or PPSD in a narrowband or broadband signal for the purpose of demonstrating compliance to the relevant regulatory limits.

5.2.3.2 Measurement of peak power with a peak power meter

The total peak output power may best be measured using a broadband peak RF power meter. The power meter shall have a video bandwidth that is greater than or equal to the EUT OBW, and utilize a fast-responding diode detector. See item r) of 4.1 for more information regarding power meter functional requirements and limitations and consult the instrumentation-specific application literature for proper set-up and use.

5.2.3.3 Measurement of peak power in a narrowband signal with a spectrum/signal analyzer or EMI receiver

This procedure can be used to measure the peak power in either a CW-like or noise-like narrowband RF signal. The measurement instrument must have a RBW that is greater than or equal to the OBW of the signal to be measured and a $VBW \geq 3 \times RBW$.

- a) Set the $RBW \geq OBW$.
- b) Set $VBW \geq 3 \times RBW$.
- c) Set $span \geq 2 \times OBW$.
- d) Sweep time $\geq 10 \times (\text{number of points in sweep}) \times (\text{transmission symbol period})$.
- e) Detector = peak.
- f) Trace mode = max hold.
- g) Allow trace to fully stabilize.
- h) Use the peak marker function to determine the peak amplitude level.

5.2.3.4 Measurement of peak power in a broadband noise-like signal using CCDF

The inherent randomness of the power peaks in a noise-like signal and the wide bandwidths associated with modern technologies makes it difficult to quantify the peak power using traditional measurement techniques. Because the peak power of a noise-like signal is predictable only on a statistical basis, a statistical measurement of the peak power is preferred.

CCDF curves provide a means for characterizing the power peaks of a noise-like signal on a statistical basis. A CCDF curve depicts the probability of the peak signal amplitude exceeding the average power level. Most contemporary measurement instrumentation offers the capability to produce CCDF curves for a noise-like input signal.

See instrumentation-specific application literature for further guidance regarding use of the CCDF capability. The following guidelines are offered for performing a CCDF measurement.

- a) Set resolution/measurement bandwidth $\geq$ OBW or specified reference bandwidth.
- b) Set the number of counts to a value that stabilizes the measured CCDF curve.
- c) Set the measurement interval as follows:
 - 1) For continuous transmissions, set to the greater of $[10 \times (\text{number of points in sweep}) \times (\text{transmission symbol period})]$ or 1 ms.
 - 2) For burst transmissions, employ an external trigger that is synchronized with the EUT burst timing sequence, or use the internal burst trigger with a trigger level that allows the burst to stabilize. Set the measurement interval to a time that is less than or equal to the burst duration.
 - 3) If there are several carriers in a single antenna port, the peak power shall be determined for each individual carrier (by disabling the other carriers while measuring the required carrier) and the total peak power calculated from the sum of the individual carrier peak powers.
- d) Record the maximum PAPR level associated with a probability of 0.1%.
- e) The peak power level is calculated from the sum of the PAPR value from step d) to the measured average power.

5.2.3.5 Measurement of peak power spectral density with a spectrum/signal analyzer or EMI receiver

The following procedure can be used with a spectrum/signal analyzer or EMI receiver to determine the PPSD.

- a) Set the analyzer center frequency to the OBW center frequency.
- b) Set the span to $2 \times$ to $3 \times$ the OBW.
- c) Set the RBW to the specified reference bandwidth
- d) Set the VBW $\geq 3 \times$ RBW.
- e) Detector = peak.
- f) Sweep time $\geq 10 \times (\text{number of points in sweep}) \times (\text{transmission symbol period})$.
- g) Trace mode = max hold.
- h) Allow trace to fully stabilize.
- i) Use the peak marker function to determine the maximum amplitude level within the specified reference bandwidth (PSD).

5.2.4 Average power and power spectral density measurements

5.2.4.1 General

Some regulatory requirements specify the RF output power and/or unwanted emissions limits in terms of total peak average power or average PSD often expressed as average conducted power, average ERP, or average EIRP. See 5.2.5.5 for guidance on determining ERP and EIRP from the measured output power data.

Total average power is often implied when the limits are stated as average conducted power, ERP, or EIRP with no further specification with respect to a reference bandwidth. When a reference bandwidth is specified in conjunction with average conducted power, ERP, or EIRP limits, then the average PSD is measured to demonstrate compliance to the relevant limits.

When the regulatory limits are expressed in terms of average power or PSD, the averaging is to be performed only over durations of active transmissions at maximum output power level. In other words, average compliance measurements shall not include averaging over periods when the transmitter is quiescent or when operating at reduced power levels (i.e., no duty cycle or duty factor reduction is permitted).

To facilitate repeatable measurements, the EUT should either be configured to transmit continuously at full power while the compliance measurement is performed, or else the measurement instrumentation should be configured to acquire data only over durations when the EUT is actively transmitting at full power. Within the context of this standard, continuous transmissions are considered to be those occurring with a duty cycle of greater than or equal to 98%. Any of the instruments discussed in 5.2.2 can be used to perform this measurement as long as this fundamental condition can be realized.

It is recognized that there will be occasions when the fundamental condition specified above cannot be realized (i.e., the EUT cannot be configured to transmit continuously and the instrumentation cannot be configured to perform measurements only during the EUT transmit on-time). Alternative measurement procedures are provided to accommodate these situations.

The following decision process outline is intended as an aid in determining the appropriate average power or PSD procedure to use with the various measuring instrumentation options and with consideration given to the spectral characteristics of the signal under measurement.

- a) If the EUT can be configured to transmit continuously (i.e., duty cycle $\geq 98\%$), then
 - 1) Use an average power meter in conjunction with the guidance provided in 5.2.4.2, or
 - 2) Use a spectrum/signal analyzer or EMI receiver in conjunction with the guidance provided in
 - i) 5.2.4.3 for measuring the total average power in a narrowband signal
 - ii) 5.2.4.4 for measuring the total average power in a broadband signal
 - iii) 5.2.4.5 for measuring the average PSD
- b) If the EUT cannot be configured to transmit continuously (i.e., duty cycle $< 98\%$), but the measurement instrument can be configured to measure only during active transmissions (i.e., through use of signal triggering or time gating), then
 - 1) Use an average power meter in conjunction with the guidance provided in 5.2.4.2, or
 - 2) Use a spectrum/signal analyzer or EMI receiver in conjunction with the guidance provided in
 - i) 5.2.4.3 for measuring the total average power in a narrowband signal
 - ii) 5.2.4.4 for measuring the total average power in a broadband signal
 - iii) 5.2.4.5 for measuring the average power spectral density

- c) If the EUT cannot be configured to transmit continuously (i.e., duty cycle < 98%) and the measurement instrument cannot be configured to measure only during active transmissions, then
- 1) Use the procedures in 5.2.4.3.4 to measure the transmitter duty cycle.
 - 2) If duty cycle is constant, use an average power meter in conjunction with the guidance provided in 5.2.4.2b), or
 - 3) Use a spectrum/signal analyzer or EMI receiver in conjunction with the guidance provided in
 - i) 5.2.4.3.2 for measuring the total average power in a narrowband signal with a constant duty cycle.
 - ii) 5.2.4.3.3 for measuring the total average power in a narrowband signal with a non-constant duty cycle.
 - iii) 5.2.4.4.2 for measuring the total average power in a broadband signal with a constant duty cycle.
 - iv) 5.2.4.4.3 for measuring the total average power in a broadband signal with a non-constant duty cycle.
 - v) 5.2.4.5 for measuring the average PSD.

When using a spectrum analyzer (or other instrument operating in spectrum analyzer mode) to perform an average power measurement with the average power (rms) display detector, the number of measurement points in each sweep shall be set greater than or equal to twice the span divided by the RBW (i.e., # measurement points $\geq 2 \times \text{span} / \text{RBW}$).

5.2.4.2 General procedure for measuring average power with an average power meter

When an average power meter is used to perform RF output power measurements, the fundamental condition that measurements be performed only over durations of active transmissions at maximum output power level applies. Thus, an average power meter can always be used to perform the measurement when the EUT can be configured to transmit continuously.

If the EUT cannot be configured to transmit continuously (i.e., burst duty cycle < 98%), then the following options can be implemented to facilitate measurement of the average power with an average power meter:

- a) A gated average power meter can be used to perform the measurement if the gating parameters can be adjusted such that the power is measured only during active transmission bursts at maximum output power levels.
- b) A conventional average power meter with no signal gating capability can also be used if the measured burst duty cycle is constant (i.e., duty cycle variations are less than or equal to $\pm 2\%$) by performing the measurement over the on/off burst cycles and then correcting (increasing) the measured level by a factor equal to $[10 \log (1/\text{duty cycle})]$. See 5.2.4.3.4 for guidance with respect to measuring the transmitter duty cycle.

See item r) of 4.1 for more information regarding power meter functional requirements and limitations, and consult the instrumentation-specific application literature for proper set-up and use.

5.2.4.3 General procedure for measuring average power of a narrowband signal with a spectrum/signal analyzer or EMI receiver

5.2.4.3.1 General

This procedure is applicable to both CW-like and noise like signals where one of the following conditions can be realized:

- The EUT can be configured to transmit continuously ($\geq 98\%$ duty cycle) at the maximum realizable output power level (e.g., use of test software), or
- Sweep triggering or signal gating can be implemented with the measurement instrument to affirm that the measurement is performed only over the duration of active, maximum power transmissions.

If one of these conditions can be realized, then the following procedure can be used to measure the total average power or the average PSD of any narrowband RF signal. If neither of these conditions can be met, then refer to the applicable alternative procedure below.

- a) Set span to $2 \times$ to $3 \times$ the OBW.
- b) Set $RBW \geq OBW$.
- c) Set $VBW \geq 3 \times RBW$.
- d) Set number of measurement points in sweep $\geq 2 \times \text{span} / RBW$.
- e) Sweep time:
 - 1) Set $\geq$ auto-couple, and enable trace averaging, or
 - 2) Set $\geq [10 \times (\text{number of points in sweep}) \times (\text{transmission symbol period})]^{26}$ and enable a single sweep (automation-compatible) measurement. The sweep time should never be faster than the auto-coupled sweep time.
- f) Detector = power averaging (rms).
- g) If the EUT can be configured to transmit continuously, then set the trigger to free run.
- h) If the EUT cannot be configured to transmit continuously, then use a sweep trigger with the level set to enable triggering only on full power bursts and configure the EUT to transmit at full power for the entire duration of each sweep. Confirm that the sweep time is less than or equal to the transmission burst duration. Setting the sweep time less than the burst duration may enable better triggering from sweep to sweep. Time gating can also be used under similar constraints (i.e., configured such that measurement data is collected only during active full-power transmissions). The sweep time should never be faster than the auto-coupled sweep time.
- i) Trace average at least 100 traces in power averaging (i.e., rms) mode if sweep is set to auto-couple. (To accurately determine the average power over multiple transmit symbols, it can be necessary to increase the number of traces to be averaged above 100 or, if using a manually configured sweep time, increase the sweep time.)
- j) Use the peak marker function to determine the maximum amplitude level.

5.2.4.3.2 Alternative procedure for measuring average power of a narrowband signal with a constant duty cycle using a spectrum/signal analyzer or EMI receiver

When the fundamental condition for average power measurements cannot be realized (i.e., the EUT cannot be configured to transmit at full-power on a continuous basis (i.e., duty cycle $< 98\%$) and the instrumentation cannot be configured to measure only during active full-power transmissions), then the following procedure can be used if the EUT duty cycle is constant (i.e., duty cycle variations are less than or equal to $\pm 2\%$):

- a) Set span to $2 \times$ to $3 \times$ the OBW.
- b) Set $RBW \geq OBW$.
- c) Set $VBW \geq 3 \times RBW$.
- d) Set number of measurement points in sweep $\geq 2 \times \text{span} / RBW$.

²⁶ Transmission symbol period is equivalent to symbol duration, which is $(1/\text{symbol rate})$.

- e) Sweep time:
 - 1) Set = auto-couple, or
 - 2) $\text{Set} \geq [10 \times (\text{number of points in sweep}) \times (\text{transmission period})]$ for single sweep (automation-compatible) measurement. The transmission period is the (on + off) time.
- f) Detector = power averaging (rms).
- g) Set sweep trigger to “free run.”
- h) Trace average at least 100 traces in power averaging (rms) mode if sweep is set to auto-couple. (To accurately determine the average power over the on and off period of the transmitter, it can be necessary to increase the number of traces to be averaged above 100 or, if using a manually configured sweep time, increase the sweep time.)
- i) Use the peak marker function to determine the maximum amplitude level.
- j) Add $[10 \log (1/\text{duty cycle})]$ to the measured maximum power level to compute the average power during continuous transmission. For example, add $[10 \log (1/0.25)] = 6 \text{ dB}$ if the duty cycle is a constant 25%.

5.2.4.3.3 Alternative procedure for measuring average power of a narrowband signal with a non-constant duty cycle using a spectrum/signal analyzer or EMI receiver

When the fundamental condition for average power measurements cannot be realized (i.e., the EUT cannot be configured to transmit at full-power on a continuous basis (i.e., duty cycle < 98%) and the instrumentation cannot be configured to measure only during active full-power transmissions), then the following procedure can be used when the EUT duty cycle is not constant (i.e., duty cycle variations are greater than $\pm 2\%$):

- a) Set the span $2 \times$ to $3 \times$ the OBW.
- b) Set $\text{RBW} \geq \text{OBW}$.
- c) Set $\text{VBW} \geq 3 \times \text{RBW}$.
- d) Set the number of points in sweep $\geq 2 \times \text{span} / \text{RBW}$.
- e) Configure a sweep time such that each display point is averaged over a period less than the transmit burst time (i.e., transmission duration > sweep time / number of measurement points in sweep) but allows for averaging over multiple symbols (e.g., by setting the sweep time $\gg$ number of measurement points in sweep $\times$ the symbol period). The sweep time should be configured toward the upper end of the range defined by: (number of points $\times$ symbol period < sweep time < transmission duration $\times$ number of measurement points).
- f) Detector = power averaging (rms).
- g) Set sweep trigger to “free run.”
- h) Trace mode = max hold.
- i) Allow trace to fully stabilize.
- j) Use the peak marker function to determine the maximum amplitude level.

5.2.4.3.4 Measurement of the transmitter (EUT) duty cycle

An oscilloscope with a diode detector that combined have sufficiently short response time to permit accurate measurements of the on and off times. A fundamental condition for all average power compliance measurements are that they be performed with the EUT transmitting continuously (duty cycle $\geq 98\%$) at maximum output power level. However, in those cases where this condition cannot be realized, then one of the alternative procedures must be selected based on whether the EUT transmitter exhibits a constant or a

non-constant duty cycle. The measurement of transmitter duty cycle shall be performed using one of the following techniques:

- a) Off times of the transmitted signal.
- b) The zero-span mode on a spectrum analyzer if the response time and spacing between bins on the sweep are sufficient to permit accurate measurements of the on and off times of the transmitted signal.²⁷

5.2.4.4 General procedure for measuring average power of a broadband signal with a spectrum/signal analyzer or EMI receiver

5.2.4.4.1 General

The EUT is considered to transmit continuously if it can be configured to transmit at a burst duty cycle of greater than or equal to 98% throughout the duration of the measurement. If this condition can be achieved, then the following procedure can be used to measure the average output power of the EUT.

This procedure can also be used when the EUT cannot be configured to transmit continuously, provided that the measurement instrument can be configured to trigger a sweep at the beginning of each full-power transmission burst, and the sweep time is less than or equal to the minimum transmission time during each burst (i.e., no burst off-time is to be included in the measurement).

- a) Set span to $2 \times$ to $3 \times$ the OBW.
- b) Set RBW = 1% to 5% of the OBW.
- c) Set VBW $\geq 3 \times$ RBW.
- d) Set number of measurement points in sweep $\geq 2 \times$ span / RBW.
- e) Sweep time:
 - 1) Set = auto-couple, or
 - 2) Set $\geq [10 \times (\text{number of points in sweep}) \times (\text{transmission period})]$ for single sweep (automation-compatible) measurement. Transmission period is the on and off time of the transmitter.
- f) Detector = power averaging (rms).
- g) If the EUT can be configured to transmit continuously, then set the trigger to free run.
- h) If the EUT cannot be configured to transmit continuously, then use a sweep trigger with the level set to enable triggering only on full power bursts and configure the EUT to transmit at full power for the entire duration of each sweep. Verify that the sweep time is less than or equal to the transmission burst duration. Time gating can also be used under similar constraints (i.e., configured such that measurement data is collected only during active full-power transmissions).
- i) Trace average at least 100 traces in power averaging (rms) mode if sweep is set to auto-couple. To accurately determine the average power over multiple symbols, it can be necessary to increase the number of traces to be averaged above 100 or, if using a manually configured sweep time, increase the sweep time.
- j) Compute the power by integrating the spectrum across the OBW of the signal using the instrument's band or channel power measurement function, with the band/channel limits set equal to the OBW band edges. If the instrument does not have a band or channel power function, then

²⁷ Burst duty cycle measurements require that the spectrum/signal analyzer has properly configured synchronization and gated inputs. A spectrum/signal analyzer provides better accuracy when the synchronization and gated pulses have rise and fall times that are faster than the rise and fall times of the signal under measurement.

sum the spectrum levels (in linear power units) at intervals equal to the RBW extending across the entire OBW of the spectrum.

5.2.4.4.2 Alternative procedure for measuring average power of a broadband signal with a constant duty cycle using a spectrum/signal analyzer or EMI receiver

When the fundamental condition for average power measurements cannot be realized (i.e., the EUT cannot be configured to transmit at full-power on a continuous basis (i.e., duty cycle < 98%) and the instrumentation cannot be configured to measure only during active full-power transmissions), then the following procedure can be used if the EUT duty cycle is constant (i.e., duty cycle variations are less than or equal to $\pm 2\%$). See 5.2.4.3.4 for guidance on measurement of duty cycle.

- a) Set span to $2 \times$ to $3 \times$ the OBW.
- b) Set RBW = 1% to 5% of the OBW.
- c) Set VBW $\geq 3 \times$ RBW.
- d) Set number of measurement points in sweep $\geq 2 \times$ span / RBW.
- e) Sweep time:
 - 1) Set = auto-couple, or
 - 2) Set $\geq [10 \times (\text{number of points in sweep}) \times (\text{transmission symbol period})]$ for single sweep (automation-compatible) measurement.
- f) Detector = power averaging (rms).
- g) Set sweep trigger to “free run.”
- h) Trace average at least 100 traces in power averaging (rms) mode if sweep is set to auto-couple. To accurately determine the average power over the on and off time of the transmitter, it can be necessary to increase the number of traces to be averaged above 100, or if using a manually configured sweep time, increase the sweep time.
- i) Compute power by integrating the spectrum across the OBW of the signal using the instrument’s band or channel power measurement function with band/channel limits set equal to the OBW band edges. If the instrument does not have a band or channel power function, sum the spectrum levels (in linear power units) at intervals equal to the RBW extending across the entire OBW of the spectrum.
- j) Add $10 \log (1/\text{duty cycle})$ to the measured power level to compute the average power during continuous transmission. For example, add $[10 \log (1/0.25)] = 6 \text{ dB}$ if the duty cycle is a constant 25%.

5.2.4.4.3 Alternative procedure for measuring average power of a broadband signal with a non-constant duty cycle using a spectrum/signal analyzer or EMI receiver

- a) Set the span to $2 \times$ to $3 \times$ the OBW.
- b) Set RBW = 1% to 5% of the OBW.
- c) Set VBW $\geq 3 \times$ RBW.
- d) Set the number of points in sweep $\geq 2 \times$ span / RBW.
- e) Configure a sweep time such that each display point is averaged over a period less than the transmit burst time (i.e., transmission duration > sweep time / number of measurement points in sweep) but allows for averaging over multiple symbols (e.g., by setting the sweep time $\gg$ number of measurement points in sweep $\times$ the symbol period). The sweep time should be configured toward the upper end of the range defined by: (number of points $\times$ symbol period < sweep time < transmission

duration $\times$ number of measurement points). Where possible (i.e., where dwell time per point is still $\gg$ symbol period and sweep time is greater than the auto-coupled sweep time), setting the dwell time per point to one half of the transmission duration may result in a more repeatable measurement (i.e., sweep time = transmission duration / 2 $\times$ number of measurement points).

- f) Detector = power averaging (rms).
- g) Set sweep trigger to “free run.”
- h) Trace mode = max hold.
- i) Allow trace to fully stabilize.
- j) Compute the power by integrating the spectrum across the OBW of the signal using the instrument’s band or channel power measurement function with band/channel limits set equal to the OBW band edges. If the instrument does not have a band or channel power function, sum the spectrum levels (in linear power units) at intervals equal to the RBW extending across the entire OBW of the spectrum.

5.2.4.5 Procedures for measuring the average power spectral density with a spectrum/signal analyzer or EMI receiver

Some regulatory requirements specify the RF output power limits in terms of maximum or average PSD, (i.e., the output power or unwanted emissions power limits are defined within a specified reference bandwidth).

When average PSD limits are specified, the same fundamental measurement condition applies as previously discussed (i.e., averaging is to be performed only over durations of active transmissions at maximum output power level). Thus, when performing this measurement, the EUT must either be configured to transmit continuously at full power while the compliance measurement is performed, or else the measurement instrumentation must be configured to acquire data only over durations when the EUT is actively transmitting at full power. In circumstances where neither of these conditions can be realized, then alternative procedures are provided for both constant duty cycle and non-constant duty cycle transmissions.

The PSD is measured following the same procedures described in 5.2.4.4 for measuring the total average power, but with the RBW set to the reference bandwidth specified by the applicable regulatory requirement, and by using the marker function to identify the maximum PSD instead of summing the power across the OBW. If the fundamental measurement condition cannot be realized, then one of the alternative procedures in 5.2.4.4.2 or 5.2.4.4.3 should be selected, based on whether the transmitter duty cycle is constant (variations $\leq \pm 2\%$) or non-constant (variations $> \pm 2\%$), respectively.

5.2.5 Adjustments to measured power levels

5.2.5.1 General

There are circumstances where it becomes necessary to make adjustments to the measured RF output power or unwanted emissions power levels to account for conditions that influence the RF power levels incident at the measurement instrumentation input port. Whenever an adjustment to the measured power is made, the rationale for the adjustment and any technical assumptions must be clearly noted in the test report. If these adjustments are already incorporated in the measured levels (i.e., through the use of amplitude offset or similar instrumentation features), a technical explanation and justification for the adjustment values applied must still be provided.

5.2.5.2 Power adjustments for factors external to the measuring instrument

Conducted measurements utilize a coaxial cable connection between the EUT RF output port and the measurement instrumentation input port. Depending on the type and length of the coaxial cable used, the attenuation associated with conducting the signal through the cable (often referred to as cable loss) could be significant. While such attenuation is often negligible when a short length of proper coaxial cable is used, it can become quite relevant where long runs of coaxial cable are used. Similarly, when external attenuators or pre-amplifiers are utilized to either reduce or amplify, respectively, the signal power under measurement, then the measured power level must be adjusted to account for the associated signal losses or gains. Include all such adjustments in the accompanying test report.

5.2.5.3 Power adjustments for EUTs with multiple transmit antenna output ports

Many contemporary EUTs utilize multiple output ports to accommodate multiple-input and multiple-output (MIMO) technologies. In these cases it may be necessary to measure the RF power at each output port and then sum the measured power levels (in linear terms) to determine the effective total RF output power. However, if output power equivalence can be demonstrated between the multiple output ports, then the power measurements can be performed on a single output port and then adjusted according to the guidelines provided in 6.4. When this option is exercised, it must be stated in the test report along with a technical explanation and justification for the particular adjustment levels applied.

5.2.5.4 Power adjustments for EUTs utilizing channel aggregation

The contemporary trend in data communications is toward ever wider bandwidth operations in efforts to improve data throughput. To realize these extended bandwidths within limited spectrum resources, some transmitters utilize channel aggregation techniques. When contiguous channels are aggregated to form a wider channel, the appropriate procedures provided herein for measuring total RF output power can be used without any need to make adjustments to the measured levels. However, when non-contiguous channels are combined to form an extended transmission channel, the appropriate procedure may have to be applied separately to each independent channel and the results summed (in linear terms) to determine the total output power.

5.2.5.5 Determining ERP and/or EIRP from conducted RF output power measurements

In many cases, RF output power limits are specified in terms of the ERP or the EIRP. Typically, ERP is specified when the operating frequency is less than or equal to 1 GHz and EIRP is specified when the operating frequency is greater than 1 GHz. Both are defined as the product of the power supplied to the antenna and its gain (relative to a dipole antenna in the case of ERP, and relative to an isotropic antenna in the case of EIRP); however, when working in decibels (i.e., logarithmic scale), the ERP and EIRP represent the sum of the transmit antenna gain (in dBd or dBi, respectively) and the conducted RF output power (expressed in dB relative to watts or milliwatts).

The relevant equation for determining the maximum ERP or EIRP from the measured RF output power is given in Equation (1) as follows:

$$\text{ERP or EIRP} = P_{\text{Meas}} + G_T \quad (1)$$

where

ERP or EIRP	effective radiated power or equivalent isotropically radiated power, respectively (expressed in the same units as P_{Meas} , e.g., dBm or dBW)
P_{Meas}	measured transmitter output power or PSD, in dBm or dBW
G_T	gain of the transmitting antenna, in dBd (ERP) or dBi (EIRP)

For devices utilizing multiple antennas, see 6.4 for guidance with respect to determining the effective array transmit antenna gain term to be used in the above equation.

The following equations demonstrate the mathematical relationship between ERP and EIRP:

- a) $ERP = EIRP - 2.15$, where ERP and EIRP are expressed in consistent units.
- b) $EIRP = ERP + 2.15$, where ERP and EIRP are expressed in consistent units.

5.2.6 Peak-to-average power ratio

Some regulatory requirements specify a PAPR limit when the output power limits are specified in terms of average power. If it becomes necessary to provide measurement data to demonstrate compliance to a PAPR limit, then the appropriate procedure from those provided in 5.2.3 shall be utilized to determine the peak power (or peak PSD) and the appropriate procedure from those provided in 5.2.4 shall be used to determine the average power (or average PSD). The data from these measurements is then used in Equation (2) to determine the PAPR of a narrowband CW-like signal. See 5.2.3.4 for guidance on determining the PAPR of a broadband noise-like signal.

$$PAPR \text{ (dB)} = P_{pk} \text{ (dBm or dBW)} - P_{Avg} \text{ (dBm or dBW)} \quad (2)$$

where

- PAPR peak-to-average power ratio, in dB
- P_{pk} measured peak power or peak PSD level, in dBm or dBW
- P_{Avg} measured average power or average PSD level, in dBm or dBW

5.2.7 Radiated power measurements

The output power and unwanted emissions regulatory limits that are typical for licensed devices presume antenna port conducted measurements are utilized when demonstrating compliance. However, it sometimes becomes necessary to measure these parameters in a radiated test set-up. This is often the case for many portable transmitting devices that utilize integral antennas, thus precluding access to an antenna port. Additionally, even when antenna-port conducted measurements can be performed, there is still a requirement to perform a radiated spurious emission test to detect and demonstrate that any case-leakage emissions from the EUT also comply with the applicable unwanted emissions limit. When radiated emissions measurements become necessary to demonstrate compliance, then the conditions specified in 5.5 shall be satisfied. The procedures provided herein for measuring RF output power and unwanted emission power can also be used in a radiated test configuration.

When performing radiated measurements, it is sometimes more convenient to perform a field strength measurement and then mathematically convert the measured field strength level to an equivalent power level for comparison to the applicable limit. Alternatively, power limit values can be mathematically converted to an equivalent field strength limit; however some regulatory agencies discourage this practice, preferring instead that the measured power levels be compared to the actual limit numerical values and units as shown in the applicable regulation. The following relationships can be used to facilitate using such radiated measurement data to demonstrate compliance to the relevant conducted output power limits:²⁸

- a) $E \text{ (dB}\mu\text{V/m)} = \text{Measured amplitude level (dB}\mu\text{V)} + \text{Cable Loss (dB)} + \text{Antenna Factor (dB/m)}$.
- b) $E \text{ (dB}\mu\text{V/m)} = \text{Measured amplitude level (dBm)} + 107 + \text{Cable Loss (dB)} + \text{Antenna Factor (dB/m)}$.
- c) $E \text{ (dB}\mu\text{V/m)} = EIRP \text{ (dBm)} - 20\log(D) + 104.8$; where D is the measurement distance (in the far field region) in m.
- d) $EIRP \text{ (dBm)} = E \text{ (dB}\mu\text{V/m)} + 20\log(D) - 104.8$; where D is the measurement distance (in the far field region) in m.

²⁸ Annex C provides equations for calculating power density, total received power, and free space path loss.

5.3 Modulation characteristics

5.3.1 General

- a) *Voice-modulated communication equipment.* A curve or equivalent data showing the frequency response of the audio modulating circuit over a range of 100 Hz to 5000 Hz shall be submitted. For equipment required to have an audio low-pass filter, a curve showing the frequency response of the filter, or of all circuitry installed between the modulation limiter and the modulated stage, shall be submitted.
- b) *Equipment that employs modulation limiting.* A curve or family of curves showing the percentage of modulation versus the modulation input voltage shall be supplied. The information submitted shall be sufficient to show modulation limiting capability throughout the range of modulating frequencies and input modulating signal levels employed.
- c) Single-sideband and independent-sideband radiotelephone transmitters that employ a device or circuit to limit peak envelope power. A curve showing the peak envelope output power versus the modulation input voltage shall be supplied. Radiotelephone transmitters equipped with a device to limit modulation or peak envelope power shall be modulated as follows. For single-sideband and independent-sideband transmitters, the input level of the modulating signal shall be 10 dB greater than that necessary to produce rated peak envelope power.
 - 1) Other than single sideband or independent sideband transmitters—when modulated by a 2500 Hz tone at an input level 16 dB greater than that necessary to produce 50% modulation. The input level shall be established at the frequency of maximum response of the audio modulating circuit.
 - 2) Single sideband transmitters in A3E or J3E emission modes—when modulated by two tones at frequencies of 400 Hz and 1800 Hz (for 3.0 kHz authorized bandwidth), or 500 Hz and 2100 Hz (for 3.5 kHz authorized bandwidth), or 500 Hz and 2400 Hz (for 4.0 kHz authorized bandwidth), applied simultaneously. The input levels of the tones shall be so adjusted that the two principal frequency components of the RF signal produced are equal in magnitude.
 - 3) Single sideband transmitters in the H3E emission mode—when modulated by one tone at a frequency of 1500 Hz (for 3.0 kHz authorized bandwidth), or 1700 Hz (for 3.5 kHz authorized bandwidth), or 1900 Hz (for 4.0 kHz authorized bandwidth), the level of which is adjusted to produce a radio frequency signal component equal in magnitude to the magnitude of the carrier in this mode.
 - 4) As an alternative to paragraph c2) and paragraph c3) of this subclause, other tones besides those specified may be used as modulating frequencies, upon a sufficient showing of need. However, any tones so chosen must not be harmonically related, the third and fifth order intermodulation products which occur must fall within the -25 dB step of the EBW limitation curve, the seventh and ninth order products must fall within the -35 dB step of the referenced curve and the eleventh and all higher order products must fall beyond the -35 dB step of the referenced curve.
 - 5) Independent sideband transmitters having two channels—when modulated by 1700 Hz tones applied simultaneously to both channels. The input levels of the tones shall be so adjusted that the two principal frequency components of the RF signal produced are equal in magnitude.
- d) *Other types of equipment.* A curve or equivalent data that shows that the equipment will meet the modulation requirements of the rules under which the equipment is to be licensed. Unless specifically referenced in the regulations, the use of higher order modulations such as OFDM or LTE or other modulations are acceptable for use. For information on the particular modulation, reference shall be made to the specific radio technology standard or the theory of operation of the device to be tested.

5.3.2 Modulation limiting test methodology

Modulation limiting is the ability of a transmitter circuit to limit the transmitter from producing deviations in excess of a rated system deviation.

- a) Connect the equipment as illustrated in Figure 1.
- b) Adjust the transmitter per the manufacturer's procedure for full rated system deviation.
- c) Set the test receiver to measure peak positive deviation. Set the audio bandwidth for ≤ 0.25 Hz to $\geq 15\ 000$ Hz. Turn the de-emphasis function off.
- d) Apply a 1000 Hz modulating signal to the transmitter from the audio frequency generator, and adjust the level to obtain 60% of full rated system deviation. This is the 0 dB reference level.
- e) Increase the level from the audio generator by 20 dB in 5 dB increments recording the deviation as measured from the test receiver in each step. Verify that the audio level used to make the OBW measurement is included in the sweep.
- f) Repeat for step e) at 300 Hz, 2500 Hz and 3000 Hz at a minimum using the 0 dB reference level obtained in step d).
- g) Set the test receiver to measure peak negative deviation and repeat step d) through step f).
- h) The values recorded in step f) and step g) are the modulation limiting.
- i) Plot the data set as a percentage of deviation relative to the 0 dB reference point versus input voltage.

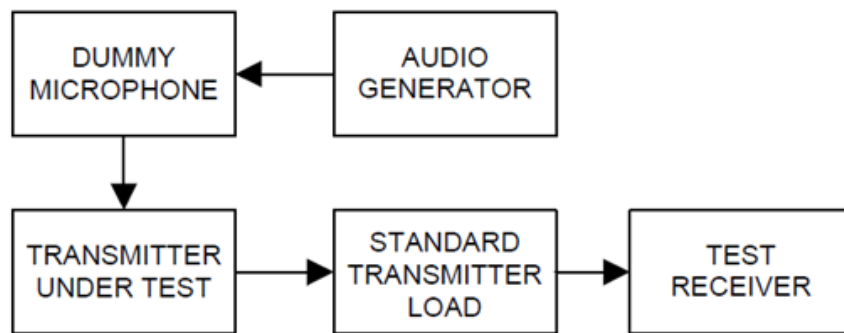


Figure 1 —Equipment set-up for modulation limiting test

5.3.3 Audio frequency response

The audio frequency response is the degree of closeness to which the frequency deviation of the transmitter follows a prescribed characteristic.

5.3.3.1 Audio frequency response test methodology—Constant deviation

Constant deviation test method (300 Hz to 3000 Hz):

- a) Connect the equipment as illustrated in Figure 2.
- b) Set the test receiver to measure peak positive deviation. Set the audio bandwidth for ≤ 50 Hz to $\geq 15\ 000$ Hz. Turn the de-emphasis function off.
- c) Set the digital multi-meter (DMM) to measure rms voltage.